EXHIBIT A

Best Available Copy

[ ]

Dr. H. Lee Martin, President
TeleRobotics International, Inc.
8410 Oak Ridge Highway
Knoxville, Tennessee 37931

Dear Dr. Martin:

We have looked at your proposed electro-optical image orientation system that you are presently developing under NASA contract and are very interested in its potential. Your exploratory efforts in the development and implementation of the algorithm that transforms a fisheye image into multiple standard views appear to verify that your concepts have a practical realization.

We are interested in developing and funding a commercialization plan for this product contingent upon the technology being reduced to practice and perform the image transformations at a rate compatible with live imaging (30 frames per second). We would anticipate entering negotiations with you concerning your specific funding needs for commercialization and product inventories one year after the beginning of your Phase II development effort. At that point in time you should have a focused estimate of the fabrication costs, inventory costs, and the initial target marketing plan.

The potential of the electro-optical viewing system for surveillance and navigation appears large. I would recommend that you augment your copyright protection with patents where possible, but the Application Specific Integrated Circuit that you mentioned should also be a strong barrier to entry. I look forward to further progress on your developments.

Sincerely,

U. S. ENTERPRISES, INC.

Walt P. Loebenberg

Walter P. Loebenberg
President

WPL:cb

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APPENDIX A

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SBIR SOLICITATION PROPOSAL COVER

PROPOSAL NUMBER
(TO BE COMPLETED BY PROPOSER)

	4 DIGIT SUBTOPIC NUMBER	LAST 4 DIGITS OF FIRM PHONE NO.	CHANGE LETTER
87-1 <*>	07 . 01	5600	____

ENTER PROPOSAL NUMBER ON APPENDICES B & C

PROJECT TITLE <*> Optimizing the Camera and Positioning System for Telerobotic Worksite Viewing.

FIRM NAME <*> TeleRobotics International, Inc.

MAIL ADDRESS <*> 8410 Oak Ridge Highway

CITY <*> Knoxville STATE <*> TN ZIP CODE <*> 37931

AMOUNT REQUESTED <*> $ 49,755.00 (PHASE I) DURATION <*> 6 MONTHS (PHASE I)

OFFEROR CERTIFIES THAT

		YES	NO
1	As defined in Section 2 of the Solicitation, this firm qualifies as a		
	1.1 Small business	X	
	1.2 Minority and disadvantaged small business		X
	1.3 Women-owned small business		X
NOTE	1.2 and 1.3 are not eligibility requirements for SBIR and the offeror may decline to indicate status by stating "Decline" across boxes		
2.	A minimum of two-thirds of the research [illegible] will be carried out within the firm if an award is made.	X	
3.	The primary employment of the principal investigator [illegible] at the time of award and during the conduct of the research.	X	
4	If the proposal does not result in an award, NASA [illegible] the proposal title and the name, address and telephone number of the Corporate Official signator below.	X	
5	If proprietary information is submitted [illegible] Proprietary Notice (below) is checked.		X
6	Proposals of similar content [illegible] have not been submitted to another agency and the details required by Section 5.11 of the Solicitation [illegible] the proposal.		

ENDORSEMENTS

	Principal Investigator	Corporate/Business Official
Typed Name <*>	Paul E. Satterlee, Jr.	Dr. H. Lee Martin
Title <*>	Vice-President	President
Telephone No. <*>	(615) 690-5600	(615) 690-5600
Signature	Paul E. Satterlee, Jr.	H. Lee Martin
Date	[ ]	[ ]

Signature of Principal Investigator — Signature of Corporate/Business Official

PROPRIETARY NOTICE (IF APPLICABLE, SEE SECTION 4.4.3.C & 6.5)

NOTICE: The information (data) on pages none of this proposal constitute a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, in the event a contract is awarded on this proposal, the Government may obtain additonal rights to use and disclose this information (data).

APPENDIX B - PROJECT SUMMARY
(INSTRUCTIONS ON REVERSE SIDE)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SBIR 87-1 SOLICITATION

TO BE COMPLETED BY PROPOSER

TOPIC • SUBTOPIC -4 TEL DIGITS - ALPHA (SEE INSTRUCTIONS)

PROPOSAL NO.: 07.01 -5600 AMOUNT REQUESTED: $ 49,755.00

TITLE OF PROJECT

Optimizing the Camera and Positioning System for Telerobotic Worksite Viewing.

TECHNICAL ABSTRACT (LIMIT 200 WORDS)

As NASA implements manipulation equipment that removes the astronaut from the direct worksite, the ability to properly view the workspace is the single most critical issue to successful teleoperated remote manipulation. With NASA's growth plan from teleoperation to autonomous operations, the viewing system must be conceived to serve both needs. This effort will develop a concept and prototype viewing system that will maximize the camera positioning/orientation capabilities while simplifying the mechanical, electrical, communications, and controls support required to implement the system. The initial focus is on the camera positioning system - how to get the camera where it is needed to provide an uncluttered view of the worksite without an overly complex and unwieldy structural support system. Mechanical camera positioning systems are large, heavy, and often unreliable. A miniature, self-contained optical-mechanical pan/tilt system with a passive positioner will be developed during the Phase I activity. A "smart" camera interface will be concepted that allows the camera signal transmission to be controlled in the following modes: frame rate (variable depending on importance of view), resolution (variable depending on type of view), and information compression (normal scan, differences only, levels only). A second pan/tilt method based on electro-optics will also be explored.

POTENTIAL COMMERCIAL APPLICATIONS OF THE RESEARCH

The mechanical concept has potential in earth-based teleoperation activities in nuclear and defense applications. The commercial potential of the electro-optical pan and tilt is significant. Many stores and banks have a camera on a pan and tilt logging scans of the facility for security purposes. The device described has the potential to be less expensive, more versatile, and more reliable than the conventional equipment now in place opening a large potential market for the device.

KEY WORDS

(LIMIT 8) Camera, robot, teleoperator, telerobot, positioning, TV viewing.

NAME AND ADDRESS OF OFFEROR

TeleRobotics International, Inc.
8410 Oak Ridge Highway
Knoxville, TN 37931
(615) 690-5600

PRINCIPAL INVESTIGATOR

Paul E. Satterlee, Jr.

3. Technical Content

a. Identification and Significance of the Innovation

Over the next decade, NASA seeks to develop the equipment necessary to allow manipulators to be remotely deployed for very dexterous tasks. These manipulators will initially be teleoperated and then evolve into autonomous devices able to accomplish construction of space structures and satellite servicing. During this evolution of technology, the importance of visual feedback will become evident, first for good human interaction via teleoperation, and then for machine sensory fusion to guide autonomous operations. The visual information channel is the single most important feedback channel available to the operator of a manipulation device. Yet, the camera positioning system is usually one of the last devices to be added to an already cluttered interface platform. With NASA strongly considering the use of 7 degree of freedom manipulation systems, the camera positioning problem becomes even more challenging as we have discovered in recent tests with a kinematically redundant manipulator mockup. Now the camera positioning system must be able to provide viewing locations that are not subtended by the equipment in the worksite between the camera and the manipulators. Two commonly considered alternatives are jointed with actively driven camera positioning appendages and end-effector mounted camera systems. These alternatives suffer from complexity, poor resource utilization (i.e., reducing the available arms for work, or providing a motion picture to the operator), and large structural size that makes it difficult to get the camera positioned in the right location. The innovation to be developed has several elements to address the problems of remote viewing, each with its own purpose. The basic goals of the innovation are:

1. Create a positioning device that can place the camera anywhere in the working volume of the manipulator and hold it there while the arms are free to work.
2. Create a pan and tilt device that is mechanically self-contained and therefore requires no consideration for obstacle avoidance once the unit is in position.
3. Create a camera control and signal interface that is flexible to minimize the transmission burden on the communications system.

The goals are commendable, and the simplicity of the proposed solution may be surprising. Over years of developing and maintaining these types of systems, we have found that the *Keep It Simple* approach is often vindicated. The positioning support system is a passive cylindrical shape retention device approximately 4 ft long. In simple terms, it is a gooseneck with a camera on one end and a mounting base on the other. The manipulator is used to position the camera end and orientation is accomplished by a miniature internal pan/tilt device. As a result of its flexibility and small size, the device can be positioned anywhere in the manipulator workspace, yet remain stationary when the manipulator is in use. The advent of smaller cameras makes it feasible to actually mount the entire camera on the end of the support (even in 1g environments) if a small pan and tilt device can be developed.

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Two potential solutions to the pan and tilt challenge will be explored. The mechanical solution is patterned after a much larger French solution developed 3 years ago. This approach places the camera inside a can and uses either a prism or mirror to accomplish miniaturized pan and tilt capabilities. Figure 1 gives the basic idea behind the positioning and orientational concept. Due to the shear size of the physical hardware that was utilized by the French, their solution is not satisfactory for this application, but a smaller system is deemed feasible with available hardware components. One critical issue to the size is the angle of motion the pan/tilt must provide. Careful determination of this range will be performed prior to the design of the device.

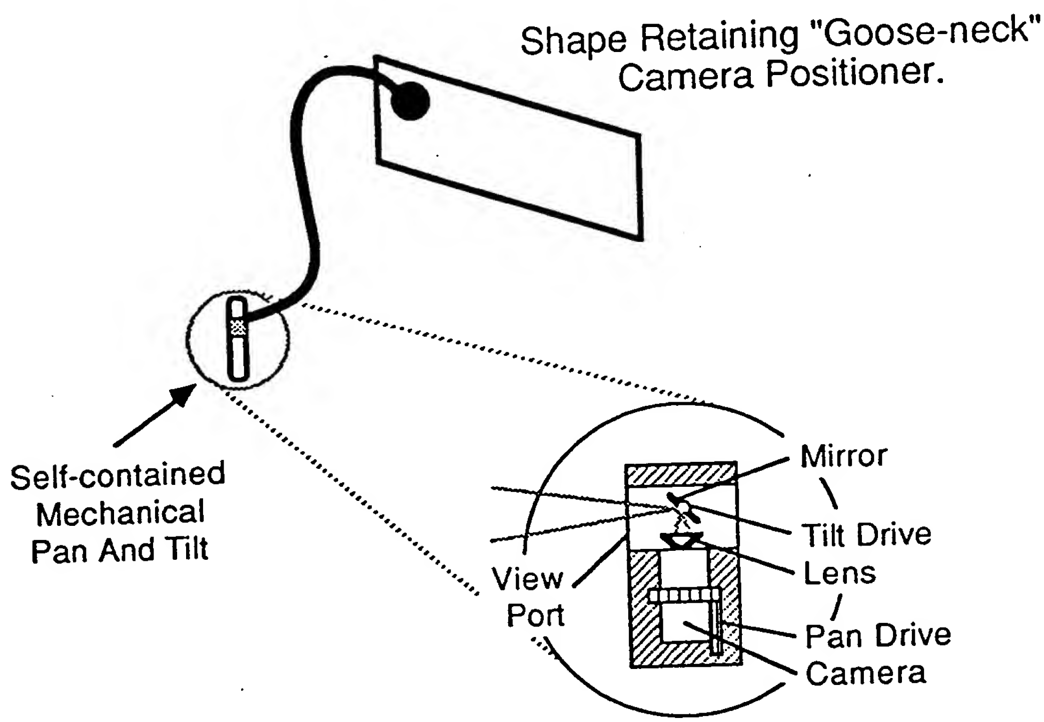

Figure 1 - Positioning and orientational concept.

A second method of accomplishing pan, tilt, and in addition zoom, is with the use of electro-optics. The physical concept is relatively straightforward. A high resolution (1024x1024 elements) digital camera is attached to a "fish-eye" lens allowing a high resolution scan of a hemisphere. A digital scan controller selects the pixel information necessary from the hemisphere to construct the desired display view at NTSC standard resolution (338x240 elements). One disadvantage that the fish-eye lens has in analog implementations is the distortion of the real world view in a manner similar to the relation between polar and rectangular coordinates. The digital processor will also be used to implement algorithms developed to remove this distortion. Figure 2 shows the basic hardware elements of the concept. To accomplish pan or 4

tilt, the displayed area is shifted throughout the viewing field as shown in Figure 3. Zoom can be accomplished by proper selection of sparse pixels to zoom in and out as shown in Figure 4. A detailed conceptual design of this type of camera system will be performed during Phase I of the activity.

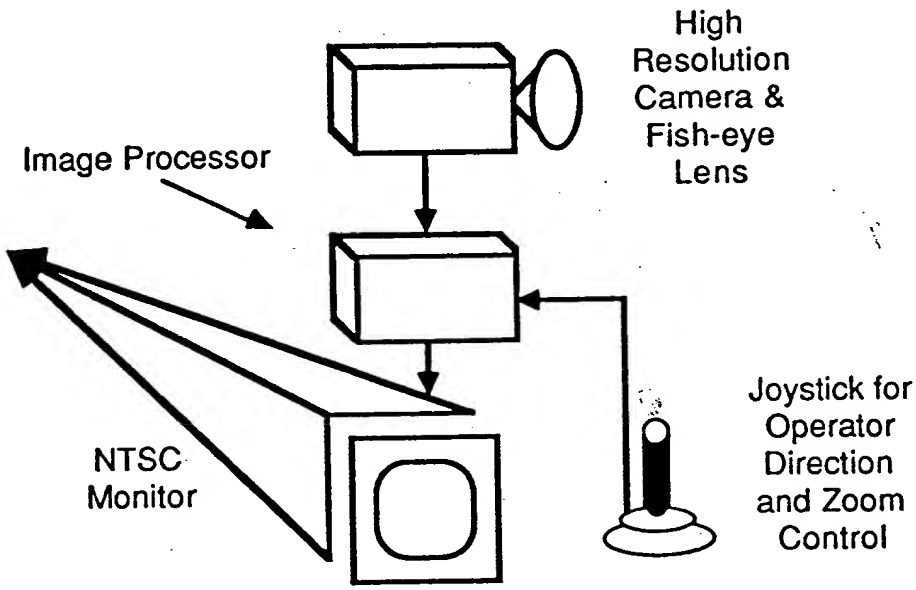

Figure 2- Hardware conceptual diagram for electro-optical pan, tilt, and zoom system.

The final objective of this systems approach to viewing is to minimize the burden which viewing systems place on the remainder of the controls, power, and communications subsystems. A smart camera controller that accepts high level serial commands and services all camera functions (pan, tilt, zoom, focus, iris, light intensity, camera power, and light power) would allow easy addition of multiple cameras to the system as needed rather than having a firmly fixed set that later turns out to be lacking for some activities. This also unburdens the higher level control systems from controlling low level functions such as drive voltage. The other advantage of a smart camera interface is the ability to perform preprocessing on the camera signal information. At levels much lower than feature extraction, there are functions/modes that the camera interface can accomplish that will unburden the ultimate performance of the communications system and other viewing processing systems. Modal operation such as frame rate control (variable depending on importance of view), resolution selection (variable depending on type of view), and basic information compression techniques (normal scan, differences only, levels only) can greatly reduce the communications burden. These and other modes will be considered in the first phase leading to a prototype development in the second phase.

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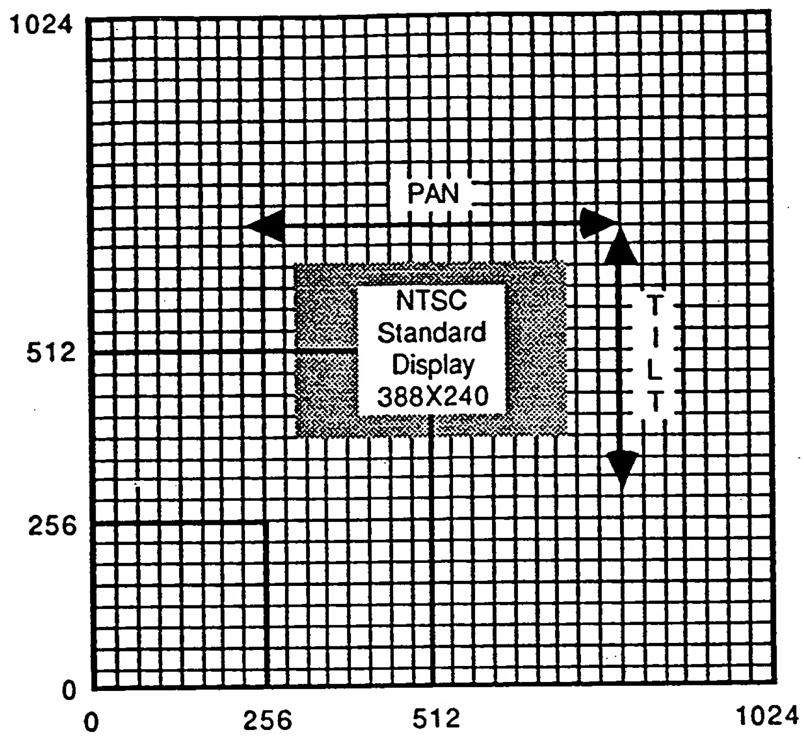

Figure 3 - Movement of standard resolution display throughout high resolution image produces electro-optical pan and tilt.

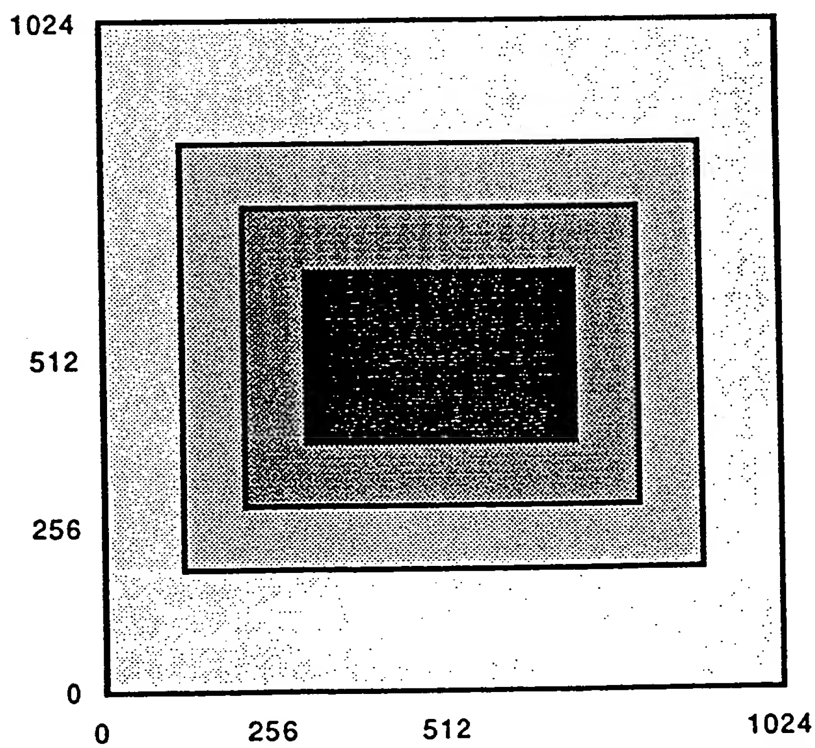

Figure 4 - Shading represents the "pixel packing" required to get automatic zoom from the Electro-optical lens system.

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b. Phase I Technical Objectives

Several technical accomplishments are planned for Phase I:

1. Hardware realization and delivery of a passive camera positioning system with excellent worksite coverage potential.
2. Hardware realization and delivery of an active, self-contained camera orientation device based on mechanical movement of the camera optics.
3. Conceptual design development of a hemispherical viewing method based on electro-optics with no mechanical mechanisms to accomplish pan, tilt, and zoom. Successful implementation would be the focus of follow-on efforts.
4. Conceptual design development of a smart camera interface that improves the ability to control, communicate, and add cameras to a working system. Successful implementation would be the focus of follow-on efforts.

Past experience with numerous teleoperated manipulator systems has shown us that viewing is of the utmost importance and that it is also the most often overlooked by systems developers who are concentrating on the manipulator arms and not the entire manipulation system. An early mockup attempt of the positioning device proposed using 2 inch diameter flexible conduit and optic fibers (H. L. Martin, 1984) demonstrated that the manipulator could readily position the camera in preparation for work tasks. Difficulties with the early attempt included: 1) the mechanical conduit was not rigid enough to maintain the set position due to its own weight and the weight of the optic fiber bundle (1/2 inch diameter and six feet long), 2) the manipulator was not adept at orienting the device once it was located (but this had to be done because the optic fiber bundle was limited to pointing in the direction of the support conduit, 3) the quality of the view through an optic fiber bundle was not comparable to direct viewing (lower resolution, lower light level, missing pixels due to breakage). The methods proposed herein directly address each of these problems using more recent technology. By mounting a miniature camera (which have both improved in performance and reduced in size and weight since the initial effort) at the end of a non-hollow flexible conduit, the system weight is reduced and the conduit strength is increased. The addition of active pan/tilt capabilities allows the orientation problem to be eliminated as long as the pan/tilt method is self-contained. The viewing quality will now be comparable to the quality provided by any other camera as no additional optical transmission devices are used.

The development of a small pan/tilt method is fundamental to the success of this innovation. The mechanical method is straightforward as described earlier and no technical difficulties are foreseen. The electro-optical approach which offers the ultimate solution is more difficult. In previous efforts, (P. E. Satterlee, 1985) an analog viewing system was developed which demonstrates the ability to perform electronic tilt through a 90 degree conic angle and provide straight ahead or near area viewing for a mobile vehicle. The method eliminates the need for any moving parts in the orientation of the camera, but is limited to the 90 degree range of motion. The

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next stage of the development as proposed for follow on work is to implement the concept in a digital system to increase the range of the viewing area, allow pan, tilt, and zooming capabilities, and provide an undistorted view to the operator. The most critical issue to the success of this effort is the speed with which the controlling microprocessor can access the camera information, reformat this information, and drive a monitor display unit. The controlling processor will be required to address 93,120 pixels of information in less than 1/30 of a second and produce a new pixel map at least every 100 milliseconds. The efforts in the first phase are to locate parts and conceptually design such a device. Once accomplished, the goals for the fourth objective become straightforward, to add intelligence to the command channel so that multiple operational modes can be performed.

c. Phase I Work Plan

The contractor shall perform research and development related to positioning, orienting, and controlling the camera system. Specific efforts will be focused on fabrication of a mechanical positioner and a self-contained camera orientation device with related development of designs for an electro-optical pan, tilt, and zoom system with no moving parts. A final effort will involve the conceptual design of an intelligent camera interface that will allow multiple performance and communications modes to be supported by the camera system. The objective of this effort being to improve the way in which camera systems are deployed by providing a mechanical demonstration unit at the completion of the Phase I effort and a conceptual design for an advanced camera interface. These objectives will be accomplished through completion of several tasks:

1. Design of a passive positioning method for cameras.
2. Selection of a camera and lens configuration for the system.
3. Design of a self-contained pan and tilt mechanism for the camera.
4. Fabrication of the mechanical positioning and orientation system.
5. Testing of the system for functionality, ease of use, and reliability.
6. Review of available literature on fish-eye lens pattern processing.
7. Selection of hardware components for an electro-optical system.
8. Detailed conceptual design of an electro-optical pan/tilt.
9. Specification of a smart camera interface.
10. Conceptual design of a smart camera interface.
11. Preparation of final report.

These tasks are to be completed on the following schedule:

Tasks 1, 2, and 6 will be completed 1 month after start of work.
Task 3 and 9 will be completed 3 months after start of work.
Tasks 4, 7, and 8 will be completed 4 months after start of work.
Task 5 and 10 will be completed 5 months after start of work.
Task 11 will be completed 6 months after start of work.

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The contractor shall provide a Final Report, a working mechanical positioner, a working mechanical orientation device, a conceptual design for an electro-optical pan/tilt, and a specification and conceptual design for a smart camera interface.

Task 1 involves locating a satisfactory passive cylindrical shape retention device. There are several potential commercial sources and a survey will be conducted to determine the best alternative. Task 2 is a similar effort to locate and procure a suitable miniature camera system that is conducive to the positioning system and potential combination with the electronics development.

Task 3 will deal with the detailed electromechanical design of a self-contained pan and tilt mechanism for the camera selected in Task 2. The output of this effort will be utilized by Task 4 to actually fabricate the positioning and orientating devices. The interfaces needed to operate the system will also be designed and fabricated during this task.

Task 5 will involve testing of the system for functionality, ease of use, and reliability while using teleoperated manipulators to operate the positioning motions of the camera.

Task 6 of this project is to review and analyze available literature on vision processing of systems equipped with "fish-eye" lenses. Dr. Earnest Hall of the University of Cincinnati has completed some studies in this field. The Jet Propulsion Laboratory has performed much work in vision systems, including stereo viewing, although thus far, the use of fish-eye optics has not been reported by them. These and other sources of information will be reviewed and a bibliography on the subject will be developed.

Selection of potential hardware components for an electro-optical system will be the focus of Task 7. Computational requirements and devices with these capabilities will be selected and incorporated into a conceptual design that addresses the potential of a pan and tilt mechanism that has no moving parts. Output of Task 8 will be the actual detailed conceptual design of an electro-optical pan/tilt. This design will include parts lists and diagrams, but will not be finalized and verified in hardware due to cost and time considerations.

Task 9 deals with the specification of a smart camera interface. It will develop the communications protocol and sensory return modes that will provide an advanced camera interface. It will also define the auxiliary interfaces required to make a camera function as an independent system (lights, motorized drives, etc.). The objective is to advance the camera interface to a level that unburdens other portions of the control system.

Task 11 will consist of preparation of the final report. All data collected from the testing will be included as well as the designs and component listing used. Enhancements to the concept will be developed and potential commercial markets will be evaluated.

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h. Related Research or R&D

TeleRobotics™ International, Inc.'s principal investigator, Paul E. Satterlee, Jr., has been involved in the design, development, and control of manipulators for the past 9 years. His present activities are in the development of control systems for mobile robotic platforms and servomanipulator systems. This includes the development of software architectures which allow manual or automatic path control of vehicles and manipulators. He has also designed numerous video interface circuits for special purpose viewing systems. His strong applicational background in electronic hardware and software systems will ensure that the designs have full operational potential.

TeleRobotics™ International Inc.'s research associate for this proposal, H. Lee Martin, has been a leader of the team developing force-reflecting servomanipulators at the Oak Ridge National Laboratory for seven years. While there, he was instrumental in the development of controls and mechanisms for servomanipulators. Dr. Martin has recently completed his PhD in the area of enhancing manipulation capabilities through the use of digital control methods. He was involved with the development of the Advanced ServoManipulator for the Department of Energy from its conception through its implementation and has received one patent on the system and has another pending. Most recently, he authored a study for NASA through the Oak Ridge National Laboratory entitled "Recommendations for the Next-Generation Space TeleRobot System". He has a patent pending on the manipulator kinematics and transmission methods of the Man Equivalent TeleRobot, (METR).

Through this extensive hardware experience, the importance of good, reliable viewing has become known and respected. Direct experience with passive viewing systems and the difficulty of developing full coverage active viewing systems have led to this proposal. Some applications of "fish-eye" technology have been performed. One used a hemispherical view to avoid obstacles in the guidance of an automated lawn mower (Hall, University of Cincinnati). A second provided for intrusion protection in a working robotic environment to replace light fences (H. L. Martin, Y-12 plant, Oak Ridge, TN). In both of these applications, the "fish-eye" lens allows large viewing volumes to be covered by a single camera system with no moving elements. The SURBOT mobile robot from REMOTEC Corp. has been outfitted with a "fish-eye" lens and electronics tilting to allow navigation with a single camera with no mechanical positioning system (P. E. Satterlee, REMOTEC). Each of these implementations have led us to believe that improved methods of viewing techniques are possible. Our extensive hands-on experience with remote manipulation indicates that the importance of well designed viewing cannot be understated.

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e. Key Personnel and Bibliography of Directly Related Work

Two people will perform the majority of the research activity on this effort. They are Paul E. Satterlee, Jr., Principal Investigator, and Dr. H. Lee Martin, Research Associate. Mr. Satterlee will perform the electronic design and development of the electro-optical viewing system and the smart camera interface. Dr. Martin will develop mechanical designs for the positioning device and the mechanical pan/tilt. Vitae of relevant activities follows.

Paul E. Satterlee, Jr. is an electrical engineer. He received his BSEE and MSEE from Louisiana State University in 1971 and 1973, respectively. He has completed all PhD coursework at the University of Tennessee. In 1984, he was the design leader of the team which won an Industrial Research Magazine's IR100 Award for the development of the first all digitally controlled servomanipulator system. This award designated this control system as one of the top 100 technical developments in the country in 1984. He worked at ORNL for 6 years in the field of microcomputers applied to real-time control problems before leaving to perform private consulting.

Mr. Satterlee is a cofounder of TeleRobotics™ International, Inc. providing electronic design, development, and fabrication expertise. He is also an expert in the language FORTH which has been used extensively in the control of servomanipulator systems. Recently, he has been the sole provider of electronic and software development support for REMOTEC Corporation's RM-10A Manipulator and the SURBOT mobile robot system. He has recently developed an analog version of the electro-optical tilting and is in the process of filing patent claims on the device. Mr. Satterlee's relevant publications include:

1. The State-of-the-Art Model M-2 Maintenance System, 1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, pp. 147-154.
2. Distributed Digital Processing for Servomanipulator Control, American Nuclear Society Conference, Remote Systems Technology Division, Washington, D. C., Nov. 1982.
3. Control Software Architecture and Operating Modes of the Model M-2 Maintenance System, 1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, pp.355-366.
4. Electromechanical Three-Axis Development for Remote Handling in the Hot Experimental Facility, American Nuclear Society Conference, Remote Systems Technology Division, San Francisco, CA, Dec. 1981.
5. SURBOT: A Surveillance Robot System for Use in Nuclear Power Plants, Robots '86 Conference, Chicago, IL, April 23, 1986.
6. Mobile Surveillance Robot System, Proceedings of the American Nuclear Society Topical Meeting on Robotics and Remote Handling in Hostile Environments, Salt Lake City, UT, March 1986.
7. Surveillance Robot for Nuclear Power Plants, Proceedings of the American Nuclear Society 33rd Conference on Remote Systems Technology, San Francisco, CA, November 1985.

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8. Analysis and Design Enhancements for the Advanced Servomanipulator, Department of Energy, January, 1987.
9. Applying the NOVIX Computer to the Real-time Control of Redundant Manipulator Systems, Department of Energy, January, 1987.

Dr. H. Lee Martin is a mechanical engineer with expertise in mechanisms and control. He received his BSME from the University of Tennessee graduating number one in his class. He obtained a MSME from Purdue University where he developed a patented state-of-charge indicator for electric vehicles. He received his PhD from the University of Tennessee in 1986. His dissertation topic was "The Reduction of Friction and Inertia Effects in Digitally Controlled Force Reflecting Servomanipulators." While an employee of the Oak Ridge National Laboratory he developed controls and mechanisms for servomanipulator systems. In 1984 he was a co-winner of Industrial Research Magazine's IR100 Award for his contributions to the development of the first all digitally controlled servomanipulator system. He was the lead control engineer for the Advanced Servomanipulator (ASM) system and has contributed to this work since its inception.

As a consultant, Dr. Martin aided in the development of the control system for the REMOTEC RM-10A servomanipulator. He has had five patent disclosures at ORNL relating to manipulator mechanisms and control strategies and he holds 2 patents. He has also played a key role in technical exchange programs with the Japanese, French, and Germans having twice represented ORNL in Japan. He founded TeleRobotics™ International, Inc. in January of 1986 to seek opportunities to transfer teleoperator technology from the laboratory to the marketplace.

He has authored or coauthored over twenty papers on the control and use of teleoperated manipulators and has edited the book *Teleoperated Robotics in Hostile Environments* published nationally by the Society of Manufacturing Engineers. A few of his relevant publications include:

1. An Advanced Remotely Maintainable Force-Reflecting Servomanipulator Concept, 1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, pp. 407-415.
2. Control and Electronic Subsystems for the Advanced Servomanipulator, 1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, pp. 417-424.
3. Distributed Digital Processing for Servomanipulator Control, American Nuclear Society Conference, Remote Systems Technology Division, Washington, D. C., Nov. 1982.
4. Joining Teleoperation with Robotics for Remote Manipulation in Hostile Environments, Robotics International, Robots 8 Conference, Detroit, MI, June 1984.
5. Automatic Camera Tracking for Remote Manipulators,1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, pp. 383-393.
6. Advanced Teleoperation in Nuclear Applications, Proceedings of the 1984 Computers in Engineering Conference, New York, 1984, pp.302-305.
7. Duty Cycle Analysis of a Human Controlled Robot, Journal of Robotic Systems, December, 1985.

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8. Recommendations for the Next-Generation Space Telerobot System, Oak Ridge National Laboratory Technical Memorandum 9951, March, 1986.
9. Workspace Intrusion Detection Device - Specifications and Implementation, Internal report, Oak Ridge National Laboratory, 1985.
10. Reduction of Friction and Inertia Effects in Digitally Controlled Servomanipulators, dissertation for the University of Tennessee, August, 1986.
11. Analysis and Design Enhancements for the Advanced Servomanipulator, Department of Energy, January, 1987.
12. Applying the NOVIX Computer to the Real-time Control of Redundant Manipulator Systems, Department of Energy, January, 1987.

f. Relationship with Future Research and R&D

Good viewing of the worksite is instrumental to successful manipulation either for human controlled operations or for computer controlled systems. Many research efforts have been focused on the human factors of viewing, color versus black and white, lighting and its relationship to viewing, stereo versus monocular viewing, and optimal viewing locations for given task configurations. These efforts are typically characterized by extensive testing and incorporate time and motion analysis of various tasks performed by a remote operator. The results are often task/environment specific and can vary widely from operator to operator, although general trends can be developed and supported. Often the superior methods that are recommended by these studies are not technically feasible in the actual environments. For example, human factors studies reveal that high resolution viewing systems are superior to standard resolution especially when inspection tasks are to be accomplished. High transmission bandwidths associated with fixed high resolution systems can cause communications problems. The ability to change scanning area electronically may offer a technically realizable solution. Human factors analysis reveals that the best fixed camera location for a single view is 45 degrees elevated and 45 degrees off the sagital plane. These conclusions result from very task dependent testing, but provide a starting point for camera base location. A positioning system that is generally located in this area, but is small and flexible enough to be placed throughout the worksite offers an exciting solution. The self-contained pan/tilt system could even be deployed like another tool and attached via a clamp and umbilical to a desirable point on the worksite. The viewing potentials are unlimited. We like to envision the operation much in the same way that a photographer sets up his studio for the best portrait and then only needs to aim and focus the camera during the actual working session.

The most important aspect of advanced research that this proposal relates to is the development of 7 degree of freedom manipulators (redundant kinematics). These new manipulators will place a tremendous need for flexible viewing techniques. Now these manipulators can work around and behind objects, but their efficiency will be diminished if the ability to see the objects is not also provided. More important than the force reflection capabilities of these manipulators is the ability of the operator or computer control system to properly see the worksite. The passive 13

flexible positioning system proposed is the safest and simplest way to provide complete flexibility for viewing the motions of future redundant kinematic manipulators. The method is "safe" because it does not rely on rigid members to hold the camera (i.e., the flexible fixture will comply easily should it collide with the worksite or a segment of the manipulator). The method is simple because no active drives are needed to position the camera. A camera positioning system with equal positional coverage would require at least four active drives and linkages, and their associated controls, power systems, decreased reliability, and bulk. Prior experience has revealed that these active, structurally intensive systems have always had a limited ability to operate in the near vicinity of the manipulators. In fact, due to collision considerations, these systems are often designed to stay out of the motion range of the viewed manipulator system. This limits the quality of the view produced and renders these viewing methods less than optimal.

Other researchers are actively developing end-effector viewing techniques. These systems utilize a wrist mounted camera to locate and track objects of interest at the end-effector. They are very useful for automatic target attachment, but the continuous motion of such a camera on an active arm makes human viewing difficult. If the view is stabilized by holding the arm motionless, the result is that the manipulator is reduced to a camera positioning system, requiring extra manipulators for multiple armed tasks. The flexible positioner in concert with the self-contained pan/tilt seeks to address this problem by allowing the manipulator to position the camera in an ideal spot for a given task and then use direct operator controls for pan and tilt to provide the viewing angles in the worksite while the task is being performed. Some may question if the need to reposition the camera frequently might interfere with the task progress and efficiency. It has been our observation that when tasks are being performed, the first activity that a human operator performs is to position the cameras so that the worksite can be properly viewed. The operator then proceeds to perform the task and the cameras are seldomly repositioned, although they are frequently reoriented. For this reason, the incorporation of pan and tilt within the camera system will allow uninterrupted task activities to be performed. Even for robotics tasks that utilize end-effector sensing, the second view in close proximity to the worksite can give useful depth information or a second verification of operations to the autonomous controller.

The development of a method for using a "fish-eye" viewing system will provide a more reliable and more versatile system to be implemented. Not only will there be no moving parts associated with the concept, but the zoom function can also be incorporated into the device. As the technology for charge coupled device (CCD) array cameras improves and the resolution increases (it has moved from 32x32 to 1024x1024 in the past 7 years and is headed for 2048x2048), the methods developed in this proposal will take advantage of this future technology.

Additionally, if the cameras were fixed to the transport base, multiple view triangulation to determine position would be more accurate since mechanical nonlinearities which accompany drive

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mechanisms (backlash, encoder resolution, compliance) are eliminated. A stereo viewing system with no moving parts based on the concept to be developed would also be an area for follow-on research and development.

g. Facilities

TeleRobotics™ International, Inc. is a new company developing human controlled electromechanical systems for remote applications. This company was formed specifically to provide creative energy in the application of robotics to hazardous environments including mechanisms, controls, the human interface, and auxiliary devices. We have been successful in attracting and completing several studies and prototype developments that will positively affect the way in which remote manipulation is accomplished in the future. The effort detailed here will rely heavily on the ideas and past experiences of the two investigators in this field. TeleRobotics™ International, Inc. has a 350 square foot laboratory facility supported by a VME bus computer supplied with a Motorola 68000 and I/O devices. Additionally, TeleRobotics™ International, Inc. has several stand alone development and design workstations that may be useful in this activity. The hardware required to perform this effort is minimal except for the specific components listed in the budget for this activity. Any additional equipment cost will be born by TeleRobotics™ International, Inc.

h. Consultants

Mechanical detailing will be provided by consulting services. Our historical rate for this service is $30/hour. Approximately 200 hours are estimated for the detailing of the self-contained pan/tilt. We also utilize local machine shop facilities in the Oak Ridge area to fabricate our prototype equipment. We have had previous hardware experience and are confident that the estimates described in this proposal are reasonable and feasible for the prototype self-contained pan and tilt system to be developed.

i. Potential Applications

Potential NASA applications are numerous. In addition to application with the dexterous telerobot being developed for space station construction, this type of imaging system could be used for docking operations on future satellites, path display on unmanned vehicles, and inspection of cluttered structures where conventional cameras could not reach. Since the unit will be smaller, lighter, and less expensive than its mechanical counterpart, the viable applications are many. Other government applications include remote environments for hazardous material handling (Department of Energy, Department of Defense).

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The commercial potential for the small, self-contained unit is also significant. Almost every "quick market" store and bank have a camera on a pan and tilt logging scans of the facility for security purposes. The device described in this proposal would be less expensive and more versatile than the conventional equipment now in place. This opens a large potential market for the device in surveillance applications. Mobile vehicles that are remotely controlled would also benefit from the development of such a device. If the advent of an autonomous automobile occurs, this type of viewing attached to a computer imaging system would provide an excellent sensory input device. The preprocessing features would allow the availability of high resolution without the processing of areas of information not of interest at that particular point in time.

4. Related Proposals or Awards

TeleRobotics™ International, Inc. has been awarded a Phase II contract from the Department of Energy, Washington, D. C. 20545 in the area of development and fabrication of an advanced teleoperated manipulator with redundant degrees of freedom. The potential development of an advanced viewing positioning system would complement this activity greatly although there is no directly related funded item in any other activity that TeleRobotics™ International, Inc. is involved. TeleRobotics™ International, Inc. is presently completing a NASA Phase I effort aimed at improving dual arm manipulation control techniques. During this effort, the importance of good viewing has been reemphasized, especially when two manipulators are used in close proximity to each other. While these efforts reveal a synergistic need for the device that we are describing herein, no related efforts are ongoing or proposed in this area.

APPENDIX C - SBIR PROPOSAL SUMMARY BUDGET
(INSTRUCTIONS ON REVERSE SIDE)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SBIR SOLICITATION

FIRM:

TeleRobotics International, Inc.

PROPOSAL NUMBER:

07.01 5600

PRINCIPAL INVESTIGATOR:

Paul E. Satterlee, Jr.

(See Instructions on Back of Form)

TOTAL PRICE

MATERIAL: * $ 12,500.00

a. Materials and Supplies - $5,500.00
b. Publication costs - $1,000.00
c. Consultant Services - $6,000.00
d. Computer Services - $0.00
e. Subcontracts - $0.00
f. Other - $0.00 *See Attatched Sheet

PERSONNEL: $ $18,000.00

PI - PES	600 hrs	$24/hr	$14,400
Engr - HLM	150 hrs	$24/hr	$ 3,600

OTHER DIRECT COSTS:* $ $ 1,600.00

Travel - $1,600.00

*See Attatched Sheet

OVERHEAD: $ $17,655.00

(55% x $32,100)

GENERAL AND ADMINISTRATIVE (G&A): $ $ 0.00

PROFIT: $ $ 0.00

TOTAL PRICE PROPOSED $ $49,755.00

TYPED NAME AND TITLE:

H. Lee Martin, President

SIGNATURE: H. Lee Martin

THIS PROPOSAL IS SUBMITTED IN RESPONSE TO NASA SBIR PROGRAM SOLICITATION 86-1 AND REFLECTS OUR BEST ESTIMATES AS OF THIS DATE.

DATE SUBMITTED

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NASA-SBIR- [ ]

APPENDIX C
SBIR Proposal Summary Budget

1. Material $ 12,500.00

a. Materials and Supplies = $5500.00
   Camera- $800.00
   Drive motors/reducers-2 @ $500 each
   Drive amplifiers-2 @ $350 each
   Mechanical fabrication of parts-$3000

b. Publication costs = $1000.00
   50 pages @ $20.00/page

c. Consultant Services = $6000.00
   System development and design check, $30.00/hour for 200 hours

d. Computer Services = $0.00

e. Subcontracts = $0.00

f. Other = $0.00

3. Other Direct Costs $ 1,600.00

Travel - $1600.00

It is anticipated that two trips will be required to properly execute this activity, one at the beginning for task definition and one at the conclusion to present the results of the effort. Each trip will require two participants and the cost is estimated at $800.00 per trip.

ATTACHMENT A
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
SBIR SOLICITATION [ ]-1
PHASE II PROPOSAL COVER SHEET

PROPOSAL NUMBER

Solicitation Number	Four Digit Subtopic No.	Last Four Digits of Firm Telephone No.
[ ]-II	07.01	5600

Enter Original Phase I Proposal No. Here & on Attach.B

PROJECT TITLE:

Electro-Optical Pan/Tilt/Zoom: A Miniature Viewing System

SUBMITTED BY: FIRM NAME: TeleRobotics International, Inc

MAIL ADDRESS: 8410 Oak Ridge Highway

CITY, STATE, ZIP: Knoxville, Tennessee 37931

1. The above organization certifies that it is a small business meeting the definition in Section 2.2 of NASA SBIR 87-1 and U.S.C. 631, and other eligibillity requirements of Section 1.3 of NASA SBIR 87-1. YES: xx NO:

2. The above organization certifies that a minimum of fifty-one percent of any Phase II contract awarded under this solicitation will be carried out within the firm. YES: xx NO:

3. The above organization has included in this proposal a commitment from a non-Federal source for follow-on funding for "Phase III." YES: xx NO:

ENDORSEMENTS

Pincipal Investigator:

Name: Dr. H. Lee Martin
Title: President
Phone: (615)-690-5600

H. Lee Martin
Signature of P.I.

Corporate/Business Official:

Name: Dr. H. Lee Martin
Title: President
Phone: (615)-690-5600

H. Lee Martin
Signature of Official

PROPRIETARY NOTICE (If applicable, see Section 6.5 of NASA SBIR 87-1

NOTICE: The information (data) on pages 3-17 of this proposal constitute a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without the permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, in the event a contract is awarded on this proposal, the Government may obtain additional rights to use and disclose this information (data).

ATTACHMENT B

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PHASE II PROPOSAL SUMMARY

TO BE COMPLETED BY OFFEROR

PROPOSAL NUMBER

SBIR [ ] -1-II 07.01.5600

NAME AND ADDRESS OF OFFEROR

TeleRobotics International, Inc.
8410 Oak Ridge Highway
Knoxville, TN 37931

PRINCIPAL INVESTIGATOR

Dr. H. Lee Martin

TITLE OF PROJECT

Electro-Optical Pan/Tilt/Zoom: A Miniature Viewing System

TECHNICAL ABSTRACT(LIMIT 200 WORDS; INCL. STATEMENT ON PHASE I RESULTS)

A necessary component of teleoperated robotic manipulation is visual feedback. The technological advances in remotely controlled vision systems lag behind developments in remote manipulators. The development of improved viewing methods are needed to enhance the overall performance of remotely operated telerobotic manipulators. In the Phase I research effort, a miniature omni-directional camera prototype was implemented that accomplishes remote viewing by simply moving the optics of the camera system rather than reorienting the entire camera. Considerable reductions in size and weight were realized in this feasibility demonstration. A theoretical analysis was performed to develop a mapping algorithm to convert a fisheye image into an undistorted object plane representation for use with digital electronics. The resulting algorithm allows pan/tilt/zoom functions to be accomplished with a fixed camera and was validated experimentally in Phase I. An electronic hardware concept was also created.

The primary goal of the Phase II effort is the hardware implementation of an electro-optical pan/tilt/zoom camera system for remote viewing. The initial research of Phase I provided the insight and theoretical background to assure the feasibility of this unique approach. The elimination of mechanical components and motion sensing devices increases the reliability while significantly reducing size, weight, and maintenance costs-all key elements to future NASA implementation of telerobotic viewing systems.

POTENTIAL COMMERCIAL APPLICATION OF INNOVATION AND THIS PROJECT

Related uses of the electro-optical pan/tilt/zoom camera system in the field of remote manipulation in addition to NASA space applications, include Department of Energy radioactive materials handling needs and Department of Defense remotely operated vehicles. In the private sector, surveillance and security systems that presently use multiple cameras and mechanical orientation and zooming methods can be replaced by this technology with cost savings and performance improvements.

FOR NASA USE ONLY

AWARD NUMBER

3. Results of the Phase I Work.

Remote manipulation incorporates many technologies to accomplish maintenance and assembly tasks without the direct presence of human beings. Other than the manipulator itself, advantageous viewing of the worksite is the most critical element for efficient teleoperation and verification of robotic task completion success. As machine vision techniques improve, worksite viewing is becoming increasingly important for autonomous manipulator operations in dynamic environments. The thrust of the Phase I effort was to explore and develop improved methods for placement and orientation of the camera system.

The major technical goals stated for the Phase I effort were:

1. Hardware realization of a passive camera positioning system with complete worksite coverage potential.
2. Hardware realization of an active, self-contained camera orientation device based on mechanical movement of the camera optics.
3. Conceptual design development of a hemispherical viewing method based on electro-optics with no mechanical mechanisms to accomplish pan, tilt, and zoom.
4. Conceptual design development of a smart camera interface that provides the ability to control, communicate, and add cameras to a working system.

In the six month Phase I period, the following major milestones were accomplished:

1. Design and fabrication of a passive camera positioning system (see Figure 1 concept and Figure 2 implementation).
2. Design and fabrication of an active, self-contained camera orientation device based on mechanical movement of the camera optics (see Figure 1 concept and Figure 2 implementation).
3. Development, validation and testing of an algorithm that creates an undistorted image from a "fisheye" image (see Figure 3 "fisheye" distorted image and Figure 4 undistorted planer section).
4. Conceptual design and feasibility analysis of a camera hardware system that undistorts the "fisheye" image in real-time (see Figure 5).

ATTACHMENT C

...NTRACT PRICING PROPOSAL COVER SHEET

1. SOLICITATION/CONTRACT/...IFICATION NO. [ ]I-II 01.5600

FORM APPROVED OMB NO. 3090-0116

...This form is used in contract actions if submission of cost or pricing data is required. *(See FAR 15.804-6(b))*

...ME AND ADDRESS OF OFFEROR *(Include ZIP Code)*

TeleRobotics International, Inc.
8410 Oak Ridge Highway
Knoxville, TN 37931

3A. NAME AND TITLE OF OFFEROR'S POINT OF CONTACT

Dr. H. Lee Martin, Pres.

3B. TELEPHONE NO.

(615)-690-5600

4. TYPE OF CONTRACT ACTION *(Check)*

- X A. NEW CONTRACT
- B. CHANGE ORDER
- C. PRICE REVISION/ REDETERMINATION
- D. LETTER CONTRACT
- E. UNPRICED ORDER
- F. OTHER *(Specify)*

...YPE OF CONTRACT *(Check)*

- [ ] FFP
- [ ] CPFF
- [ ] CPIF
- [ ] CPAF
- [ ] FPI
- [ ] OTHER *(Specify)*

6. PROPOSED COST (A+B=C)

A. COST	B. PROFIT/FEE	C. TOTAL
$ 463,805	$ 32,466	$ 496,271
$451,365	x 7% $31,595	$482,960

...ACE(S) AND PERIOD(S) OF PERFORMANCE

Knoxville, Tennessee; 24 month ARO

...ist and reference the identification, quantity and total price proposed for each contract line item. A line item cost breakdown supporting this recap is re...uired unless otherwise specified by the Contracting Officer. *(Continue on reverse, and then on plain paper, if necessary. Use same headings.)*

. LINE ITEM NO.	B. IDENTIFICATION	C. QUANTITY	D. TOTAL PRICE	E. REF.
1	Design, development and delivery of Electro-Optical pan/tilt/zoom miniature viewing system Proposal	1	496,271	Attached

9. PROVIDE NAME, ADDRESS, AND TELEPHONE NUMBER FOR THE FOLLOWING *(If available)*

...CONTRACT ADMINISTRATION OFFICE

B. AUDIT OFFICE

... WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS WORK? *(If "Yes," identify)*

[X] YES [ ] NO

11A. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT? *(If "Yes," complete Item 11B)*

[X] YES [ ] NO

11B. TYPE OF FINANCING *(✓ one)*

[ ] ADVANCE PAYMENTS [X] PROGRESS PAYMENTS [ ] GUARANTEED LOANS

...2. HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR THE SAME OR SIMILAR ITEMS WITHIN THE PAST 3 YEARS? *(If "Yes," identify item(s), customer(s) and contract number(s))*

[ ] YES [X] NO

13. IS THIS PROPOSAL CONSISTENT WITH YOUR ESTABLISHED ESTIMATING AND ACCOUNTING PRACTICES AND PROCEDURES AND FAR PART 31 COST PRINCIPLES? *(If "No," explain)*

[X] YES [ ] NO

14. COST ACCOUNTING STANDARDS BOARD (CASB) DATA *(Public Law 91-379 as amended and FAR PART 30)*

... WILL THIS CONTRACT ACTION BE SUBJECT TO CASB REGULATIONS? *(If "No," explain in proposal)*

[X] YES [ ] NO

B. HAVE YOU SUBMITTED A CASB DISCLOSURE STATEMENT (CASB DS-1 or 2)? *(If "Yes," specify in proposal the office to which submitted and if determined to be adequate)*

[ ] YES [X] NO

... HAVE YOU BEEN NOTIFIED THAT YOU ARE OR MAY BE IN NONCOMPLIANCE WITH YOUR DISCLOSURE STATEMENT OR COST ACCOUNTING STANDARDS? *(If "Yes," explain in proposal)*

[ ] YES [X] NO

D. IS ANY ASPECT OF THIS PROPOSAL INCONSISTENT WITH YOUR DISCLOSED PRACTICES OR APPLICABLE COST ACCOUNTING STANDARDS? *(If "Yes," explain in proposal)*

[ ] YES [X] NO

This proposal is submitted in response to the RFP contract, modification, etc. in Item 1 and reflects our best estimates and/or actual costs as of this date.

15. NAME AND TITLE *(Type)*

H. Lee Martin, President

16. NAME OF FIRM

TeleRobotics International, Inc.

17. SIGNATURE

H. Lee Martin, PRESIDENT

18. DATE OF SUBMISSION

[ ]

NSN 7540-01-142-9845 1411-101 STANDARD FORM 1411 (10-83)

Line Item Cost Breakdown-ELECTRO-OPTICAL PAN/TILT/ZOOM CAMERA SYSTEM - Total Cost ($496,271)

Direct Material ($97,120)

Subcontracted Items

$20,000 (Modifications to camera mechanical configurations, printed circuit board fabrication)

Standard Commercial Items

$77,120 (see attached list of items)

Raw Material (None)

Direct Labor ($205,400)

PI-HLM (hours-2000, rate-$26/hr, total-$52,000)

SDZ (hours-3400, rate-$21/hr, total-$71,400)

PES (hours-2000, rate-$26/hr, total-$52,000) 28,875

TRI support staff (hours-1500, rate-$20/hr, total-$30,000)

Indirect Costs (~~$133,510~~) 123,240

Labor overhead and general and administrative overhead last two year's average: 65% 60%

Other Costs ($27,775)

Travel

4 update trips, two people each, one night 25

(8*(400-airfare+75-hotel+25-ground trans.+50 per diem))

= ~~$4400~~ $4080

Short Courses

Efficient preparation for DSP development (2@$1500)

Report Preparation

Reproduction costs for reports ($375)

Consultants

Don Bouldin, Dan Newport for ASIC chip developments ($20,000) $19,950

Profit/Contingency (7% of total = ~~$32,466~~) 31,545

Royalties ($0.00)

Facilities Capital Cost of Money ($0.00)

Materials Support Information

The items listed below are the major items required for the development of an electro-optical pan/tilt/zoom camera system described in the accompanying proposal. While the effort has many parts, the single line item deliverable is the camera system described. Where available, cost estimates have been obtained from data sheets or phone conversations with vendors. Engineering judgement has been used based on prior experience to estimate the cost of fabrication activities since no detailed design is presently available for obtaining price quotations.

Subcontracted material items: ($20,000)

Camera packaging modification 2@$5000

Multilayer printed circuit board fabrication 5 @ $2000

Total	$20,000

Standard Commercial Items: ($77,120)

Fisheye Lens	Nikor 8 mm *f*/2.8 180°	1865.00	2
VRAM	TC524256Z-10 1 Mbit	75.00	32
Video Control	TMS34061-12	40.00	2
DRAM Memory	64K Bytes 35 nS	50.00	2
SRAM Memory	64K Bytes 35 nS	50.00	2
Dual-Port RAM	4K Bytes 70 nS	125.00	2
Microprocessor	N80C196 Intel	40.00	4
Misc. Logic	F series logic	3000.00	1
DSP	DSP56001	300.00	4
DSP	Analog Devices ADSP2100	300.00	4
Flash A/D	AD9012	100.00	4
MMI Platform	Mac II	6000.00	2
Digitizer	256 gray scales	6000.00	1
Software	Programming tools	2000.00	1
Monitor	HDTV resolution	5000.00	2
PAL Programmer		1500.00	1
Camera	CCD	10000.00	2

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DSP Development System	5000.00	1
100 MHz Scope	8000.00	1
TOTAL	77,120.00	

10. Representations, Certifications, and Other Statements of Offerors

Required representations, certifications, and other statements of the offer are attached per the SBIR Program Proposal instructions.

11. Follow-on Funding Commitment for Phase III

A venture group out of Clearwater, Florida has been contacted concerning the progress and promise of our Phase I efforts. U.S. Enterprises, Inc. is a firm with real-estate and high tech holdings throughout Florida and now expanding into the Southeast. They have substantial backing ($90 million in assets) and have an interest in the omni-directional viewing system for commercial surveillance applications. Our conversations have been very fruitful thus far. A letter of commitment from U.S. Enterprises follows.

TeleRobotics International, Inc. also has interests in the commercialization of the fisheye electro-optical imaging system for remotely operated vehicles. We plan to develop algorithms that will support autonomous navigation via image analysis to further the commercial acceptance of this technology.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
SBIR[ ]-II
REPRESENTATIONS AND INSTRUCTIONS

OFFERER: TELEROBOTICS INTERNATIONAL, INC.

1 52.203-2 CERTIFICATE OF INDEPENDENT PRICE DETERMINATION
[ ]

(a) The offeror certifies that -
(1) The prices in this offer have been arrived at independently, without, for the purpose of restricting competition, any consultation, communication, or agreement with any other offeror or competitor relating to (i) those prices, (ii) the intention to submit an offer, or (iii) the methods or factors used to calculate the prices offered;
(2) The prices in this offer have not been and will not be knowingly disclosed by the offeror, directly or indirectly, to any other offeror or competitor before bid opening (in the case of a sealed bid solicitation) or contract award (in the case of a negotiated solicitation) unless otherwise required by law; and
(3) No attempt has been made or will be made by the offeror to induce any other concern to submit or not to submit an offer for the purpose of restricting competition.
(b) Each signature on the offer is considered to be a certification by the signatory that the signatory -
(1) Is the person in the offeror's organization responsible for determining the prices being offered in this bid or proposal, and that the signatory has not participated and will not participate in any action contrary to subparagraphs (a)(1) through (a)(3) above; or
(2) (i) Has been authorized, in writing, to act as agent for the following principals in certifying that those principals have not participated, and will not participate in any action contrary to subparagraphs (a)(1) through (a)(3) above HARRY LEE MARTIN, PRESIDENT (insert full name of person(s) in the offeror's organization responsible for determining the prices offered in this bid or proposal and the title of his or her position in the offeror's organization);
(ii) As an authorized agent does certify that the principals named in subdivision (b)(2)(i) above have not participated, and will not participate in any action contrary to subparagraphs (a)(1) through (a)(3) above; and
(iii) As an agent, has not personally participated, and will not participate, in any action contrary to subparagraphs (a)(1) through (a)(3) above.
(c) If the offeror deletes or modifies subparagraph (a)(2) above, the offeror must furnish with its offer a signed statement setting forth in detail the circumstances of the disclosure.

(End of Provision)

2 52.203-4 CONTINGENT FEE REPRESENTATION AND AGREEMENT [ ]

(a) Representation. The offeror represents that, except for full-time bona fide employees working solely for the offeror, the offeror -
(NOTE: The offeror must check the appropriate boxes. For interpretation of the representation, including the term "bona fide employee", see Subpart 3.4 or the Federal Acquisition Regulation.)

(1) ( ) has, (X) has not, employed or retained any person or company to solicit or obtain this contract; and

(2) ( ) has, (X) has not, paid or agreed to pay to any person or company employed or retained to solicit or obtain this contract any commission, percentage, brokerage, or other fee contingent upon or resulting from the award of this contract.

(b) Agreement. The offeror agrees to provide information relating to the above Representation as requested by the Contracting Officer and, when subparagraph (a)(1) or (a)(2) is answered affirmatively, to promptly submit to the Contracting Officer -

(1) A completed Standard Form 119, Statement of Contingent or Other Fees, (SF 119); or

(2) A signed statement indicating that the SF 119 was previously submitted to the same contracting office, including the date and applicable solicitation or contract number, and representing that the prior SF 119 applies to this offer or quotation.

(End of Provision)

3 18-52.203-70 CONTRACTS BETWEEN NASA AND FORMER NASA EMPLOYEES [ ] (NASA/FAR SUPPLEMENT)

The offeror represents that he or she ( ) is, or (X) is not, an individual who was employed by NASA during the past two (2) years, or a firm in which such former employee is a partner, principal officer, majority shareholder, or which is otherwise controlled or predominantly staffed by such former employees.

(End of Provision)

4 52.215-6 TYPE OF BUSINESS ORGANIZATION [ ]

The offeror or quoter, by checking the applicable box, represents that -
(a) It operates as (X) a corporation incorporated under the laws of the State of TENNESSEE, ( ) an individual, ( ) a partnership, ( ) a nonprofit organization, or ( ) a joint venture; or
(b) If the offeror or quoter is a foreign entity, it operates as ( ) an individual, ( ) a partnership, ( ) a nonprofit organization, ( ) a joint venture, or ( ) a corporation, registered for business in ________________.
country

(End of Provision)

5 52.215-11 AUTHORIZED NEGOTIATORS [__ __]

The offeror or quoter represents that the following persons are authorized to negotiate on its behalf with the Government in connection with this request for proposals or quotations: (list names, titles, and telephone numbers of the authorized negotiators).

H. LEE MARTIN, PRESIDENT (615)-690-5600

(End of Provision)

6 52.215-20 PLACE OF PERFORMANCE [__ __]

(a) The offeror or quoter, in the performance of any contract resulting from this solicitation, ( ) intends, (X) does not, intend (check applicable block), to use one or more plants or facilities located at a different address from the address of the offeror or quoter as indicated in this proposal or quotation.
(b) If the offeror or quoter checks "intends" in paragraph (a) above, it shall insert in the spaces provided below the required information:

Place of Performance (Street Address, City, County, State, Zip Code)	Name and Address of Owner and Operator of the Plant or Facility if Other than Offeror or Quoter

(End of Provision)

7 52.219-1 SMALL BUSINESS CONCERN REPRESENTATION [__ __]

The offeror represents and certifies as part of its offer that it (X) is, ( ) is not a small business concern and that (X) all, ( ) not all end items to be furnished will be manufactured or produced by a small business concern in the United States, its territories or possessions, Puerto Rico, or the Trust Territory of the Pacific Islands. "Small business concern," as used in this provision, means a concern, including its affiliates, that is independently owned and operated, not dominant in the field of operation in which it is bidding on Government contracts, and qualified as a small business under the size standards in this solicitation.

(End of Provision)

8 52.219-2 SMALL DISADVANTAGED BUSINESS CONCERN REPRESENTATION [__ __]

(a) Representation. The offeror represents that it ( ) is, (X) is not, a small disadvantaged business concern.
(b) Definitions.
"Asian-Indian American," as used in this provision, means a United States citizen whose origins are in India, Pakistan, or Bangladesh.

"Asian-Pacific American," as used in this provision, means a United States citizen whose origins are in Japan, China, the Philippines, Vietnam, Korea, Samoa, Guam, the U.S. Trust Territory of the Pacific Islands, the Northern Mariana Islands, Laos, Cambodia, or Taiwan.

"Native American," as used in this provision, means American Indians, Eskimos, Aleuts, and native Hawaiians.

"Small business concern," as used in this provision, means a concern, including its affiliates, that is independently owned and operated, not dominant in the field of operation in which it is bidding on Government contracts, and qualified as a small business under the criteria and size standards in 13 CFR 121.

"Small disadvantaged business concern," as used in this provision, means a small business concern that (1) is at least 51 percent owned by one or more individuals who are both socially and economically disadvantaged, or a publicly owned business having at least 51 percent of its stock owned by one or more socially and economically disadvantaged individuals and (2) has its management and daily business controlled by one or more such individuals.

(c) Qualified groups. The offeror shall presume that socially and economically disadvantaged individuals include Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Asian-Indian Americans, and other individuals found to be qualified by the SBA under 13 CFR 124.1.

(End of Provision)

9 52.219-3 WOMEN-OWNED SMALL BUSINESS REPRESENTATION [ ]

(a) Representation. The offeror represents that it ( ) is, (X) is not, a women-owned small business concern.

(b) Definitions.

"Small business concern", as used in this provision, means a concern, including its affiliates, that is independently owned and operated, not dominant in the field of operation in which it is bidding on Government contracts, and qualified as a small business under the criteria and size standards in 13 CFR 121.

"Women-owned", as used in this provision, means a small business that is at least 51 percent owned by a woman or women who are U.S. citizens and who also control and operate the business.

(End of Provision)

10 52.220-1 PREFERENCE FOR LABOR SURPLUS AREA CONCERNS [ ]

(a) This acquisition is not a set aside for labor surplus area (LSA) concerns. However, the offeror's status as such a concern may affect (1) entitlement to award in case of tie offers or (2) offer evaluation in accordance with the Buy American Act clause of this solicitation. In order to determine whether the offeror is entitled to a preference under (1) or (2) above, the offeror must identify, below, the LSA in which the costs to be incurred on account of manufacturing or production (by the offeror or the first-tier subcontractors) amount to more than 50 percent of the contract price.

EAST TENNESSEE

(b) Failure to identify the locations as specified above will preclude consideration of the offeror as an LSA concern. If the offeror is awarded a contract as an LSA concern and would not have otherwise qualified for award, the offeror shall perform the contract or cause the contract to be performed in accordance with the obligations of an LSA concern.

(End of Provision)

11 52.222-21 CERTIFICATION OF NONSEGREGATED FACILITIES [___ ___]

(a) "Segregated facilities", as used in this provision, means any waiting rooms, work areas, rest rooms and wash rooms, restaurants and other eating areas, time clocks, locker rooms and other storage or dressing areas, parking lots, drinking fountains, recreation or entertainment areas, transportation, and housing facilities provided for employees, that are segregated by explicit directive or are in fact segregated on the basis of race, color, religion, or national origin because of habit, local custom, or otherwise.
(b) By the submission of this offer, the offeror certifies that it does not and will not maintain or provide for its employees any segregated facilities at any of its establishments, and that it does not and will not permit its employees to perform their services at any location under its control where segregated facilities are maintained. The offeror agrees that a breach of this certification is a violation of the Equal Opportunity clause in the contract.
(c) The offeror further agrees that (except where it has obtained identical certifications from proposed subcontractors for specific time periods) it will -
(1) Obtain identical certifications from proposed subcontractors before the award of subcontracts under which the subcontractor will be subject to the Equal Opportunity clause;
(2) Retain the certifications in the files; and
(3) Forward the following notice to the proposed subcontractors (except if the proposed subcontractors have submitted identical certifications for specific time periods):

NOTICE TO PROSPECTIVE SUBCONTRACTORS OF REQUIREMENT FOR CERTIFICATIONS OF NONSEGREGATED FACILITIES

A Certification of Nonsegregated Facilities must be submitted before the award of a subcontract under which the subcontractor will be subject to the Equal Opportunity clause. The certification may be submitted either for each subcontract or for all subcontracts during a period (i.e., quarterly, semiannually, or annually).

NOTE: The penalty for making false statements in offers is prescribed in 18 U.S.C. 1001.

(End of Provision)

12 52.222-22 PREVIOUS CONTRACTS AND COMPLIANCE REPORTS [___ ___]

The offeror represents that -
(a) It (X) has, ( ) has not, participated in a previous contract or subcontract subject either to the Equal Opportunity clause of this solicitation, the

clause originally contained in Section 310 of Executive Order No. 10925, or the clause contained in Section 201 of Executive Order No. 11114;
(b) It (X) has, ( ) has not, filed all required compliance reports; and
(c) Representations indicating submission of required compliance reports, signed by proposed subcontractors, will be obtained before subcontract awards.

(End of Provision)

13 52.222-25 AFFIRMATIVE ACTION COMPLIANCE [ ]

The offeror represents that (a) it (X) has developed and has on file, ( ) has not developed and does not have on file, at each establishment, affirmative action programs required by the rules and regulations of the Secretary of Labor (41 CFR 60-1 and 60-2), or (b) it ( ) has not previously had contracts subject to the written affirmative action programs requirement of the rules and regulations of the Secretary of Labor.

(End of Provision)

14 USE OF GOVERNMENT-OWNED PROPERTY (45-200) [ ]

(a) The offeror does ( ) does not (X) intend to use in any contract awarded as a result of this solicitation any Government-owned (1) facilities, (2) special test equipment or (3) special tooling.

(b) If the offeror does intend to use any of the above items in any resultant contract, the following information required by FAR 45.205(b) must be furnished by the offeror as a part of the proposal:

(1) Identification and quantity of each item and the value thereof.

(2) Identification of the Government contract under which acquired and written permission for its use from the cognizant Contracting Officer.

(3) Rental provisions.

(4) The date of the last review by the Government of its property control and accounting system and describe actions taken to correct any deficiencies found.

(5) A statement that the offeror has reviewed, understands, and can comply with all property management and accounting procedures in the solicitation, FAR Subpart 45.5, and NASA/FAR Supplement Subparts 18-45.5, 18-45.70, and 18-45.71.

(6) A statement indicating whether or not the costs associated with subparagraph (5) above are included in its cost proposal.

(7) The dates during which the property will be available for use, and if used in two or more contracts, the amounts of respective uses in sufficient detail to support proration of the rent.

(End of Text)

15 RELATED PROPOSALS AND AWARDS REPRESENTATION

The offeror, by checking the applicable box, represents that it [ ] has previously been or is currently being, [X] has not previously been and is not currently being, paid for essentially equivalent or similar work by any agency of the Federal Government. (See Section 5.11 of NASA Solicitation SBIR 87-1.)

(End of Text)

(END OF PRESENTATIONS)

SIGNATURE BLOCK

By signature below, the offeror certifies that all representations and certifications (No. 1-15) contained in this "Representations and Instructions" are complete and accurate as required; is aware that award of any contract to the offeror or bidder shall be considered to have incorporated the applicable representations and certifications by reference in accordance with Federal Acquisition Regulation 15.406-1(b), and is aware of the penalty prescribed in 18 U.S.C. 1001 for making false statements in proposals.

Harry Lee Martin

Signature

Harry Lee Martin

Typed Name

PRESIDENT

Title

Date

5. Parts location and selection of the major electronic elements that will comprise the hardware realization of the electro-optical pan/tilt/zoom camera system.

In the past, large pan and tilt units and bulky cameras have been the only source of viewing feedback from the remote site. These camera orientation and positioning systems have often been as complicated as the manipulators themselves. A miniaturized alternative, shown conceptually in Figure 1 and prototyped in the Phase I effort, is a self-contained camera that accomplishes remote viewing orientation by simply moving the optics of the camera system, rather than reorienting the entire camera. The savings in subtended volume for camera orientation throughout the range of viewing motion is significant, reducing from 4 cubic feet for typical systems to 1/4 of a cubic foot for the prototype system. The reduction in size also results in a reduction in weight allowing the entire viewing package including the positioning system to weigh less than 20 pounds. A mechanical prototype of the concept was fabricated in Phase I and is shown in Figure 2. The mechanical-optical pan and tilt of the unit is accomplished by a lens mounted mirror. The entire package is then placed on a counterbalanced four-bar linkage that allows the camera to be located in the worksite by using one of the manipulators. This combination of simplicity and flexibility offers a viable alternative to approaches that use fixed location camera systems or complex articulated arms that crowd the worksite and interfere with the manipulation systems.

The second major activity of the Phase I research was to further reduce the size and complexity of the camera system by accomplishing the pan, tilt, and zoom capabilities without moving parts. The conceptual design of an innovative method of remote viewing which uses state-of-the-art electronic components was developed. The new concept uses a fisheye lens and high resolution digital camera to control all camera functions including electronic pan, tilt, and zoom capabilities. A complete hemispherical field of view is provided without any mechanical movement of the camera and can be undistorted by the electronics that operate the camera.

The Charge Coupled Diode (CCD) camera makes use of a new high resolution CCD array image sensor recently developed by Toshiba Corp. The new image sensor provides an order of magnitude increase in the number of image elements integrated on a single chip. An electro-optical camera was conceptually designed and the transformation algorithms developed that allow the new CCD sensor and a "fisheye"

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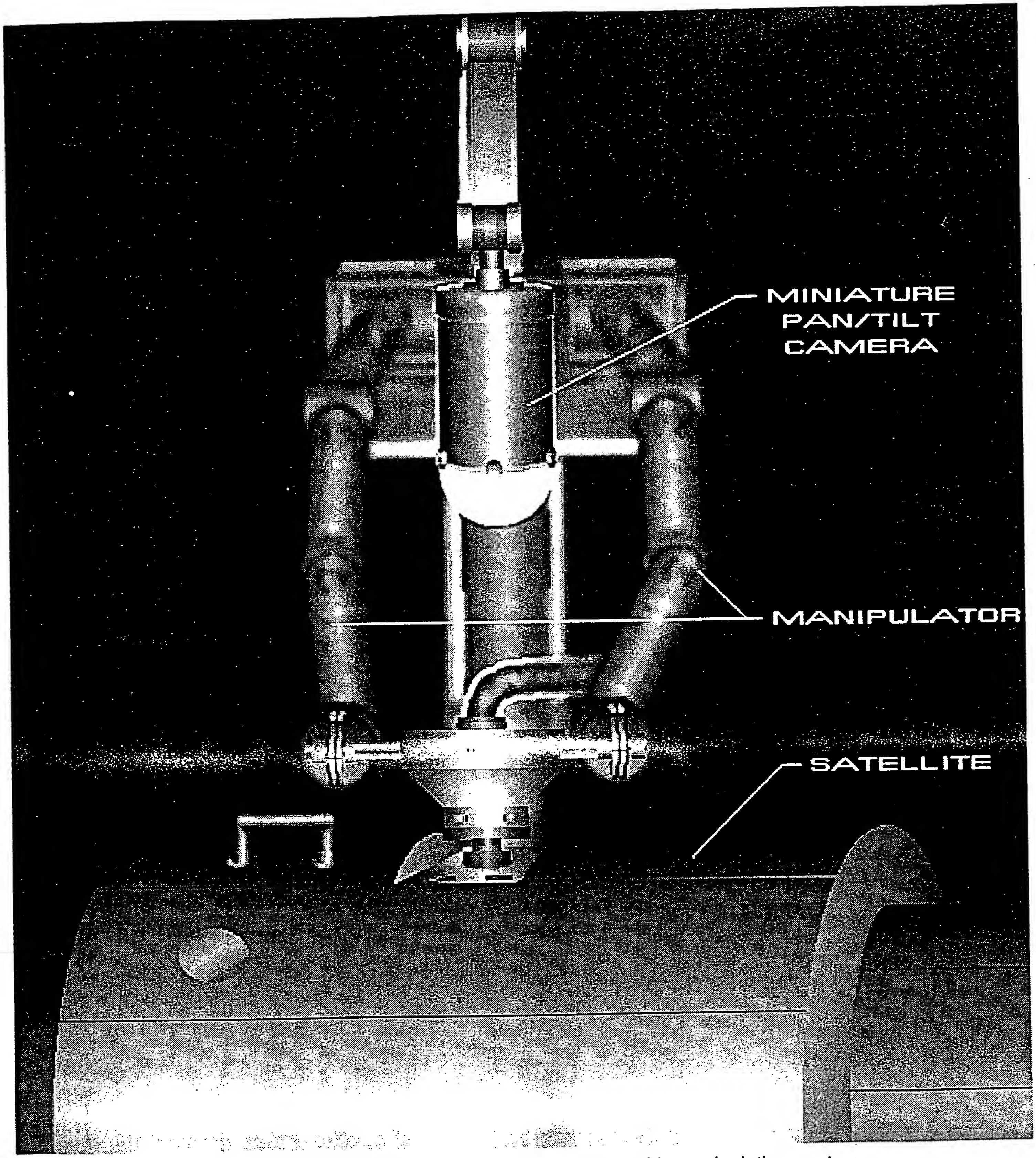

Figure 1 - Self-contained camera concept shown with manipulation system.

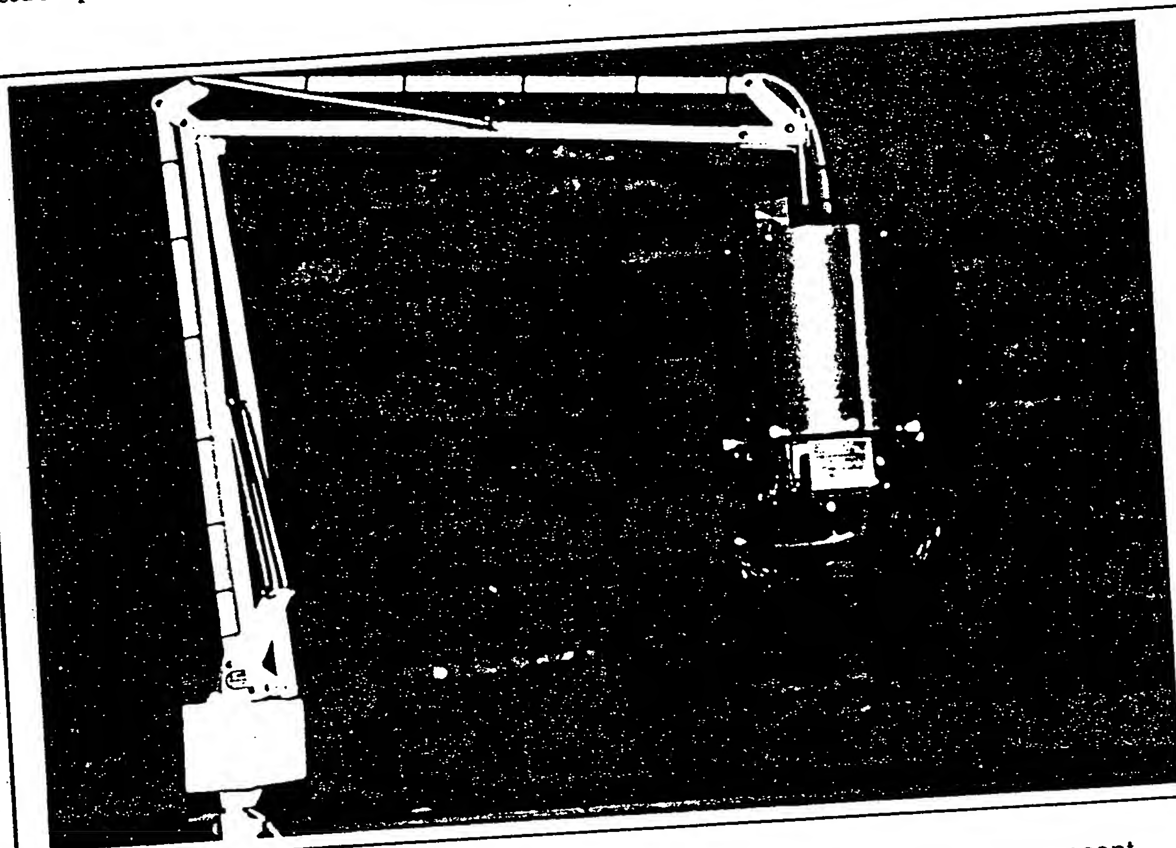

Figure 2 - Mechanical demonstration of the self-contained camera concept.

lens equipped camera to achieve electro-optical pan, tilt, and zoom over a complete 2π steradian (hemispherical) field of view.

Utilizing digital image transformation techniques, the fisheye image is transformed from a highly distorted circular projection into an undistorted object plane representation. In the Phase I report, the transformation equations required to undistort the polar to rectangular views for electro-optical pan and tilt were developed. A sample fisheye image was scanned using a 300 dots per inch binary optical scanner. A software implementation of the algorithm was developed using a Macintosh II and the C programming language. The personal computer implementation of the algorithm validated the theoretical analysis as can be seen in Figures 3 and 4. Figure 3 shows the complete 2π steradian fisheye image that was used as the basis for testing the algorithm. The view shown in Figure 4 is the result of applying the algorithm using the normal view or parallel axis view direction.

Not only was the algorithm developed, but it was implemented and validated during this Phase I effort. The validation process resulted in a complete software implementation of the algorithm. To process an image required 30 seconds to accomplish using a Motorola 68020 based general purpose microprocessor with its associated operating system

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overhead. Our analysis reveals that the utilization of a digital signal processor (DSP) which is solely designed for the implementation of this algorithm will provide significant (1-2 orders of magnitude) speed increases. By performing the transformation once to create a look-up table (in less than one second), the subsequent image transformations can be accomplished at the 30 frames per second rate. The electronic methodology needed to implement this concept in real-time has

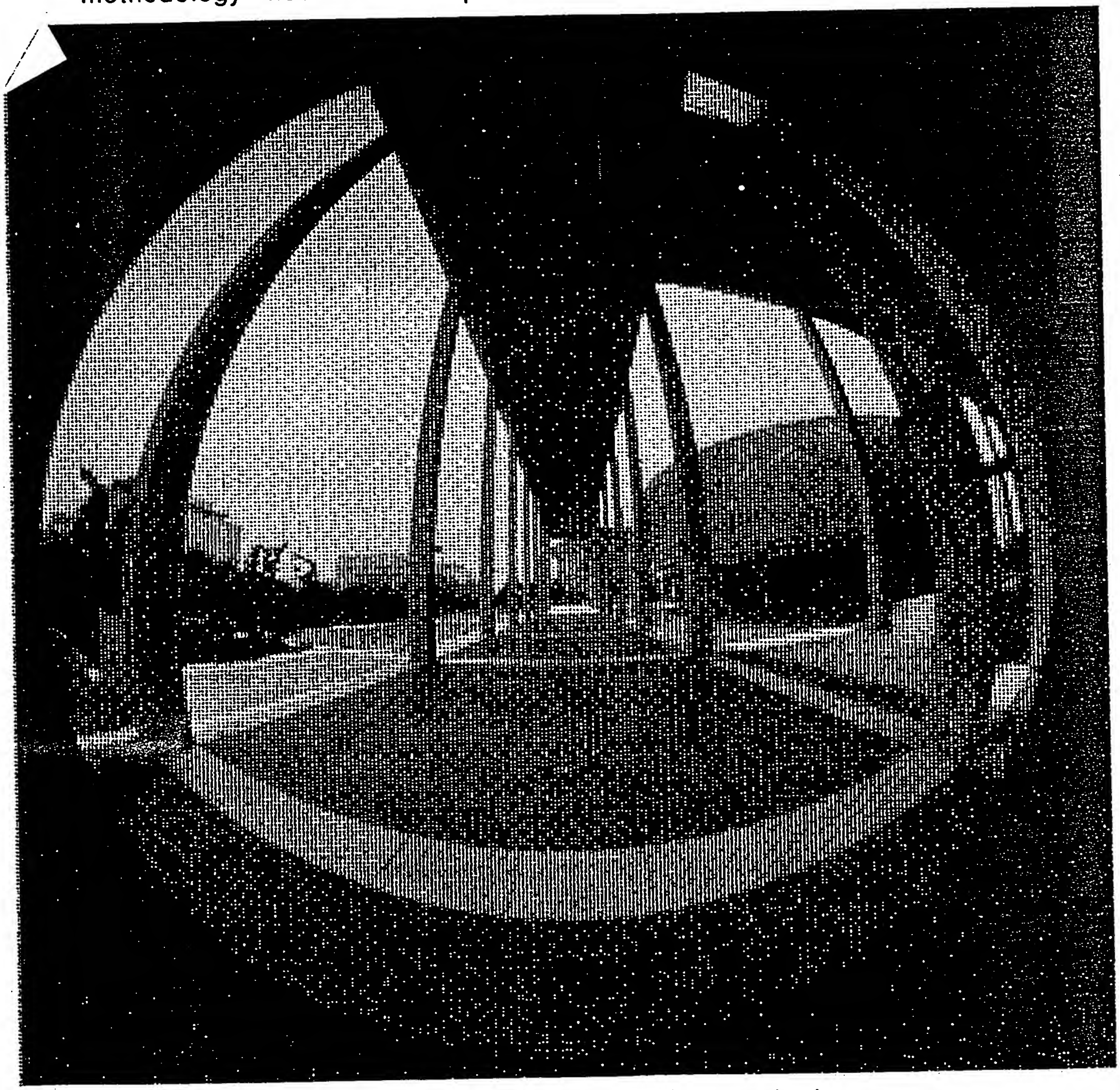

Figure 3 - Scanned fisheye image prior to de-skewing.

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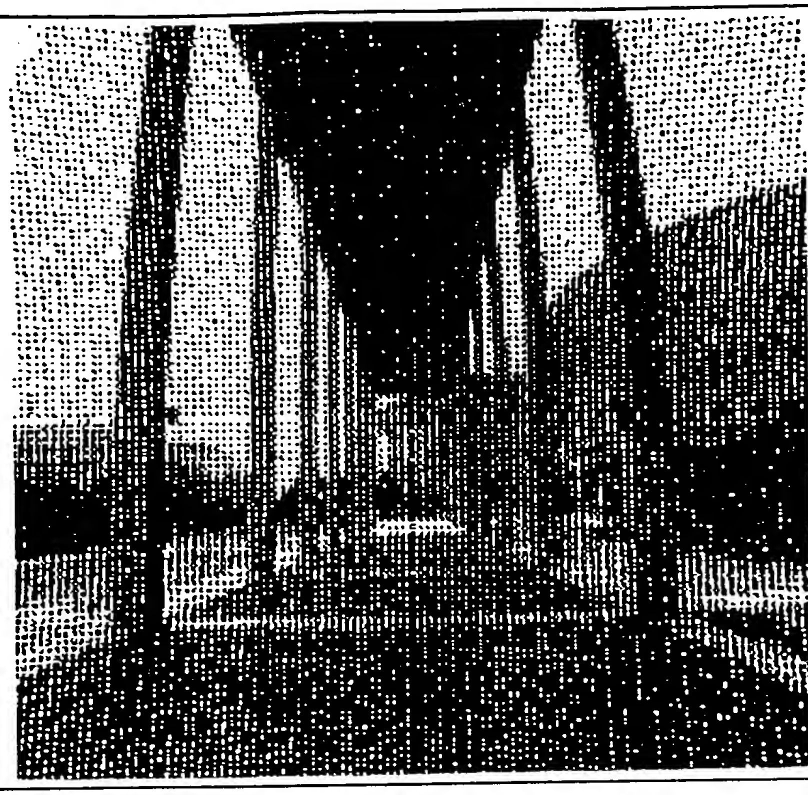

Figure 4 - Scanned fisheye image after application of algorithm.

been researched, availability confirmed, and several concept diagrams of the design have been developed for Phase II development and application.

Since the Phase II proposed effort builds on the results of our algorithm development from the Phase I effort that undistorts the hemispherical image into a planer image at the orientation and zoom desired, the essence of the theoretical analysis that was fully developed and presented in the Phase I final report follows:

A theoretical analysis was performed on the relationship between the image projected by a prime lens or "fisheye" lens and the original object plane. The results verified that the distortion present in a fisheye image can be removed for a region of interest by using a direct transformation. The algorithm for transformation of the fisheye circular image onto a flat object plane provides a forward calculation and mapping of the object plane onto the fisheye image without the need for iterative calculations. The parameters for the algorithm are determined from a knowledge of the digitized image radius alone. Rotation of axes allow pan and tilt over a 2π steradian field of view. The transformation algorithm is defined in terms of an orthogonal set of axes in object plane coordinates mapped into a circle within an

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orthogonal set attached to the image plane. The final equations as developed in the Phase I report are presented below.

$$x = \frac{Ru}{\sqrt{u^2+v^2+m^2R^2}} \quad (1)$$

$$y = \frac{R(v\cos\beta - mR\sin\beta)}{\sqrt{u^2+v^2+m^2R^2}} \quad (2)$$

Where:

R = radius of image circle in pixels

m = magnification

u,v = object plane coordinates

x,y = transformed image plane coordinates

β = zenith angle

These two equations represent a mapping rule that maps the object plane image point with coordinates (u,v) onto the image plane with coordinates (x,y). In the equations, R is the radius of the image circle in pixels as projected by a fisheye lense onto the CCD array image sensor. The zenith angle or tilt angle measured from the normal axis of the camera is given as β and varies over an angle of 0° to 90°. The equations also provide the capability to zoom by varying m. A value of m=1 corresponds to the object plane being placed tangential to the effective fisheye image sphere with radius R. Increasing values of m provide image magnification or the effect of zooming in on the region of interest. The addition of a rotation of axes in the image plane provides the capability to pan over 360° angle and is implemented in the two following equations.

$$x' = x\cos\theta - y\sin\theta + x_{offset} \quad (3)$$

$$y' = x\sin\theta + y\cos\theta + y_{offset} \quad (4)$$

Where:

x' = horizontal pixel address

y' = vertical pixel address

θ = rotation angle within image plane

Equations 1, 2, 3 and 4 provide the capability to pan, tilt, and zoom anywhere within a 180° hemispherical field of view.

The hardware design of the transformation algorithm uses video RAM memory to perform the transformation in real-time. A set of transformation buffers address each pixel of the CCD frame buffer during frame transfers. The XY transformation buffers eliminate the need for calculation of each pixel map in real-time. Once the map has been calculated and stored in the transformation buffer, it remains constant until a new viewing direction is needed. Transform map updates can occur simultaneously and asynchronously with the display readout and update functions. In actuality, three functions associated with the image transformation occur independently - the readout of the CCD image sensor into the frame buffer, the display update or mapping of the CCD frame buffer to the transformed image, and the update of the transformation map. A high speed digital signal processor performs the calculations and stores the pixel address map in the transformation buffers when the view orientation is changed.

It is apparent from this initial effort, that a digital signal processor can accomplish the necessary transformations from the fisheye view to the desired pan and tilt view in approximately 1/3 of a second. By creating a vectored table look up between the fisheye view and the desired view the display rate can be accomplished at 30 Hz non-interlaced or 60 Hz interlaced rates. After computation of the table look up, transformed images at a normal rate of 30 frames per second can be achieved to provide normal views of the remote environment.

Further effort in the specification of a "smart" camera interface completed the Phase I activity. The concept of the smart camera is one that can be communicated with and operated in a number of states. Control of the frame rate, the image resolution, the image type (such as frame differencing and vector quantization), and self-diagnosing camera functions are all key features of the smart camera concept. An additional opportunity that a smart camera interface addresses is the limited communications bandwidth that is available in most freespace remote applications.

The smart camera supports operating modes that meet the demands of the viewing application. Central views can be provided at high resolution and full frame rate, while peripheral views can be transmitted less frequently and at a lower resolution. Camera operating modes can be shifted at the request of the operator or supervisory computer to meet the present needs of the task. The resulting system gives maximum viewing capability with minimum

communications requirements, a key consideration for future space manipulation systems which will rely on freespace transmission in already crowded frequency bands.

In summary, the Phase I efforts resulted in the following significant accomplishments:

1. Design and fabrication of a passive positioning method for cameras;
2. Selection of a camera and lens configuration for the system;
3. Design of a self-contained pan and tilt mechanism for the camera;
4. Fabrication of the mechanical positioning and orientation system;
5. Testing of the system for functionality and ease of use;
6. Review of available literature on fisheye pattern processing;
7. Selection of hardware components for an electro-optical system;
8. Detailed conceptual design of an electro-optical pan/tilt;
9. Specification of a smart camera interface;
10. Conceptual design of a smart camera interface;
11. Theoretical development of image transformation algorithm;
12. Software validation of algorithm;
13. Development of software application for analyzing fisheye images, and;
14. Preparation of the final report.

All major objectives of the Phase I activity were met within the time schedules. The conceptual design of the electro-optical camera provided the theoretical background to continue Phase II efforts and to consider the actual design and implementation of the all electronic hemispherical viewing system. The conceptual design analysis of the electro-optical camera demonstrated the feasibility of the implementation. Many of the major elements necessary to complete the design are available off the shelf. The key component of importance is the new CCD image sensor recently developed by Toshiba Corp. The new sensor is expected to be available well within the time frame of the Phase II effort.

The fundamental conclusion of the Phase I work is that an electro-optical pan/tilt/zoom camera system is feasible, realizable, and offers

a solution needed to advance remote telerobotic implementations. The demonstration of the mechanical implementation confirmed our assumptions that a smaller package would be useful in the confined remote environment. The success of the algorithm in the undistortion of a fisheye image gave confidence to our assertions that this could be accomplished with reasonable computational systems. Our development of a conceptual design that located the major electronic elements and analyzed the timing requirements leads us to believe that a unique and serviceable electro-optical pan/tilt/zoom viewing system is realizable by our company in the Phase II effort.

4. Phase II Technical Objectives and Approach

The realization and delivery of a "smart" electro-optical pan/tilt/zoom remote camera system for passive viewing in remotely operated environments is the major goal of the Phase II research and design effort. The electro-optical camera concept provides a compact and innovative means of actively viewing the entire manipulator workspace. The Phase II effort will extend the theoretical, algorithmic, and conceptual developments provided in the Phase I effort to a hardware implementation of an electro-optical pan/tilt/zoom camera. Further developments for the communications interface providing a variable scan rate, variable resolution capability, and multiple simultaneous views from the same camera will be implemented as the Phase II effort proceeds. The major technical objectives are outlined below.

OBJECTIVE: Stable long-term performance of orientation and camera lens controls. *APPROACH:* Due to the digital implementation, no calibration is ever needed for the orientation system (i.e., no analog sensors, and no gear mechanisms to periodically adjust or lubricate). The fully digital camera system also provides long-term stability from the imaging standpoint. Electronic gain rather than mechanical iris adjustment can control the iris function and the infinite depth of field of the fisheye lens eliminates the need for an active focus mechanism. The varied pixel scan capability automatically provides zoom with no moving parts.

OBJECTIVE: Minimize the size of the unit and make all orientations accomplished internally with no moving parts. *APPROACH:* The use of the electro-optical pan/tilt/zoom methodology conceived in Phase I will be implemented in a compact package that has no moving parts. A digital signal processor will be developed to transform the hemispherical image into useful views.

OBJECTIVE: Provide a 10X zoom capability without a motorized zoom on the camera. *APPROACH:* By using a high resolution sensor and the algorithm developed in Phase I, a ten times zoom capability can be supported with single pixel resolution. Higher magnifications (20-40X) can be accomplished by reducing the output resolution. The concept uses selective pixels to obtain a view to the magnification required on a lower resolution viewing monitor (i.e. the 1000*1000 CCD array is scanned and zoomed as needed to provide the 350 line NTSC standard resolution output associated with most TV monitors).

OBJECTIVE: Develop a user interface to the system that is responsive and easy to operate. *APPROACH:* The electro-optical camera system must be easy to operate including functions of pan, tilt, zoom, and operating mode. An operator interface will be developed during the course of the effort providing direct access to these capabilities using a graphical interface. The design goal is to provide a camera that can be selected and controlled with minimum operator learning and effort. A straightforward man-machine interface approach will be utilized that provides high level interface control of all camera functions. The operator should be able to select a viewing direction by simply touching a region on a control screen. Icon based control functions and draggable scroll bars can provide zoom and rotation within the hemispherical field of view.

OBJECTIVE: Develop a "smart" camera interface that supports the usage of several of these cameras on a single communications channel. *APPROACH:* A communications interface for modal operation including varied frame rate, varied resolution, frame difference transmission, and camera status transmission will be developed to provide a system compatible with NASA's long-term needs. This will reduce communications requirements and cable handling considerations.

OBJECTIVE: Reduce the signal, power, and drive cabling required to operate a remote camera. *APPROACH:* A reduction in the amount of signal cabling and power consumption will be gained by the elimination of the motion drives and motion sensors. Pan and tilt axis drives and motorized zoom, focus, and iris needed to completely control the camera view are eliminated by the electro-optical pan/tilt/zoom system proposed. This also results in cost savings because of the reduction in the instrumentation and electronic interfaces. Positioning accuracy is not lost because the electro-optical camera view can be aimed with a minimum resolution of 0.2° electronically.

OBJECTIVE: Replace multiple cameras with a single electro-optical camera system. *APPROACH:* A dual ported video memory with the

capacity for providing dual split-image transforms simultaneously will be implemented to allow tracking of multiple views using a single camera. Reducing the number of cameras in a given installation thus provides another means by which the electro-optical viewing system will minimize installation costs.

At the completion of the Phase II effort a prototype electro-optical camera system ready for commercialization will be available and the first unit will be delivered to the NASA sponsor. Since this will be the main objective of the effort, a description of the major technical components is provided along with a block diagram to describe the approach. The camera will provide electronic viewing within a hemispherical field of view. The viewing angle (pan and tilt) and image zoom will be accomplished by electronic means. Added features of the camera will allow rotation of the image under software control as well as unique commands to provide features such as region zooms and split-image viewing. A block diagram of the electro-optical camera is shown in Figure 5. The camera consists of the following main functional blocks:

- Fisheye equipped CCD camera
- CCD frame buffer block
- Translation buffer block
- Algorithm processor block
- Data compression block
- High speed communication block
- Command channel communication block
- Peripheral interface block

The CCD interface consists of the CCD image sensor interface and a CCD image frame buffer for intermediate storage of the complete CCD image. The image conversion block is responsible for undistorting the fisheye circular image and providing serial pixel readout to the data compression block. The data compression block transforms the 8-bit serial pixel data from the CCD frame buffer to a compressed form and temporarily stores the data in a hold buffer for later communication. The image and control processor consists of a high speed digital signal processor that calculates the X and Y pixel conversion addresses that are stored in the image conversion block. A two link serial communication interface provides a networked camera system using a high speed video transmission link and a low speed control link.

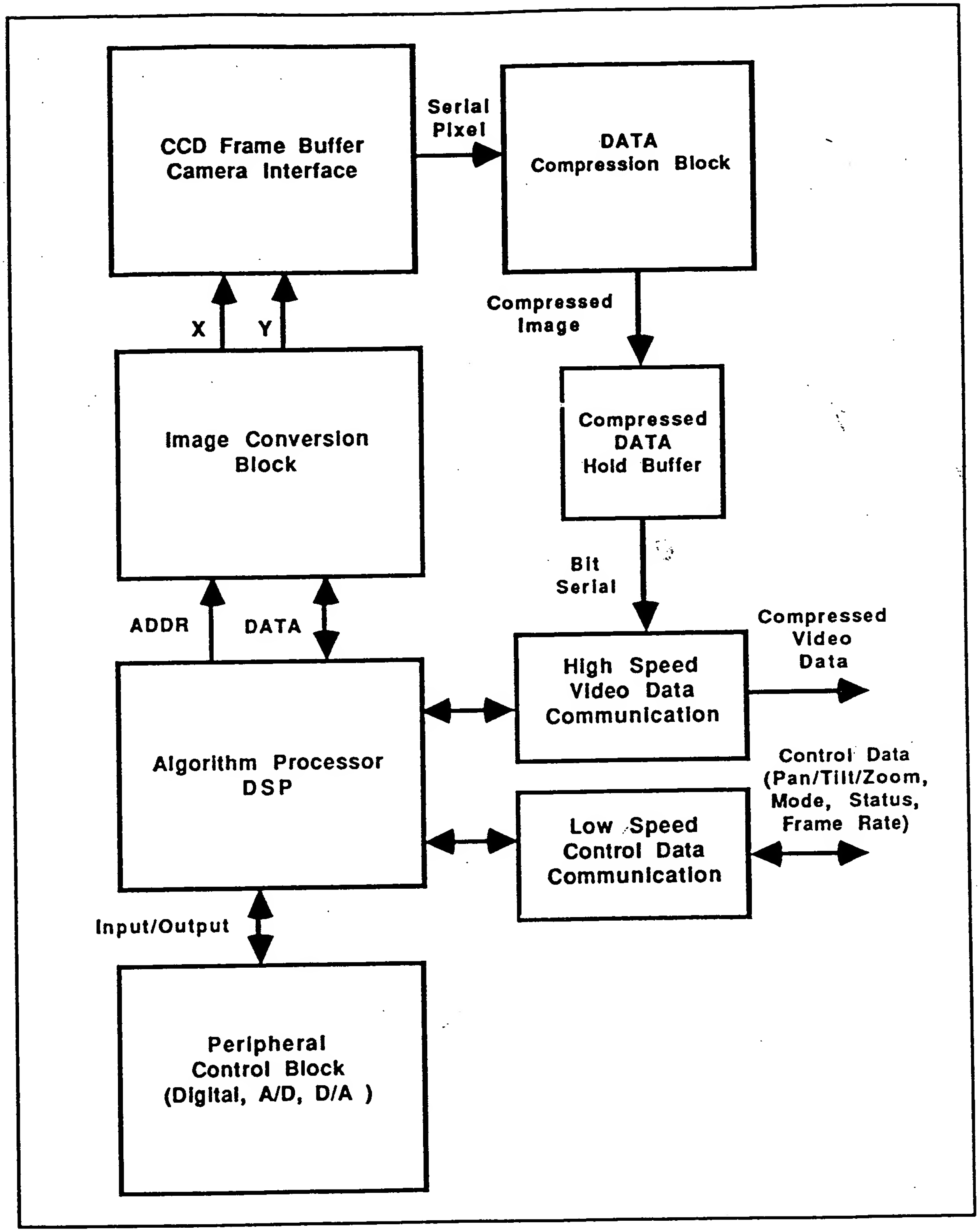

Figure 5 - Electro-Optical Camera Block Diagram

There are two important keys to the implementation that will guarantee its success. First, the Digital Signal Processing (DSP) implementation of the developed algorithm will significantly speed the operation assuring the conversion time of less than 1 second (we actually anticipate that this conversion can be done in less than 0.3s, but only hardware verification will prove this). Secondly, using a table look up transformation system, the 30 Hz throughput of the viewing system transformation can be guaranteed for a continuous image. The table look up is a novel approach that will assure that the camera response is satisfactory for human operations as well as computer vision autonomy.

An operator control station will be implemented that provides control of the camera network and selection of specific views. The operator control station will consist of a personal computer with full color display capabilities to provide complete icon based graphics for camera control. The Phase II goal is to provide a single man-machine interface platform that enables control and display of the camera views on the personal computer monitor. The frame rates of each of the cameras will be controlled to obtain the best viewing situation and maximum available bandwidth utilization for the data communication channel. Each camera can be asked to provide views at varying frame rates. The operator display station would provide a constant display in between frames for cameras that are transmitting at slower frame rates.

5. Phase II Statement of Work

The electro-optical camera design provides the opportunity to advance the state-of-the-art in high speed digital image processing and video data bandwidth compression. The major objectives of Section 4 are all related to successful implementation of the electro-optical pan/tilt/zoom camera system shown in the block diagram of Figure 5. The worktask milestones revolve around implementation of the detailed designs that support the block diagram of Figure 5. These tasks are outlined below. A performance schedule and description of the task goals have also been included.

(1.0) Procure and modify high resolution CCD camera with fisheye mounting;

(2.0) Develop algorithm software control features;

(3.0) Design and prototype command channel link;

(4.0) Design and prototype CCD frame buffer block;

(5.0) Design and prototype translation buffer block;
(6.0) Design and prototype algorithm processor block;
(7.0) Development of man-machine interface platform;
(8.0) Design and prototype data compression block;
(9.0) Design and prototype high speed communication link;
(10.0) Design and prototype A/D interface to CCD camera.

Figure 6 gives the schedule and milestones for the Phase II effort described herein.

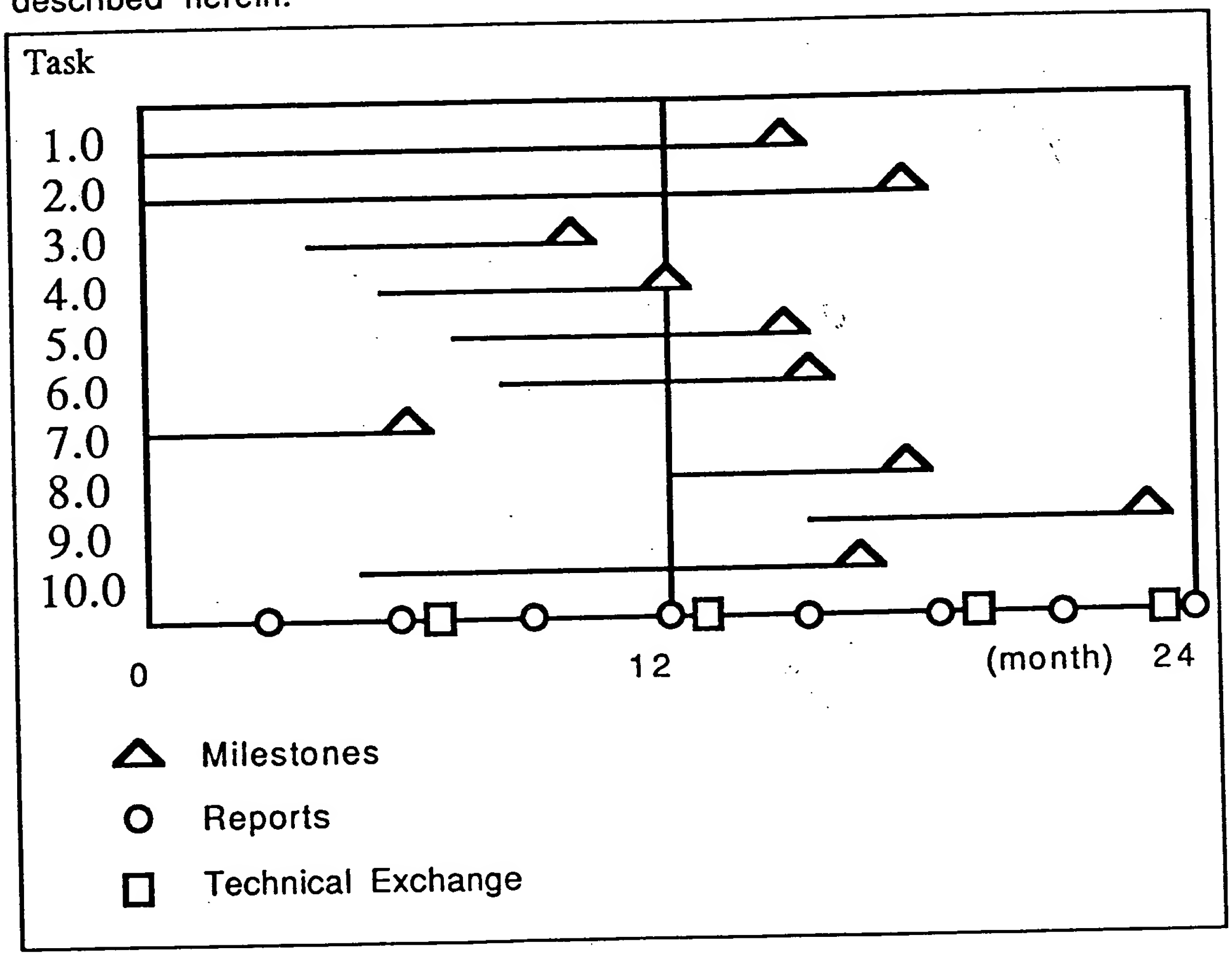

Figure 6 - Schedule for development of the electro-optical pan/tilt/zoom camera system.

The milestones for each of the subtasks are:

1) High resolution CCD and fisheye operational
2) Final software including data compression complete
3) Command link functional

4) Frame buffer block functional
5) Translation buffer block functional
6) Processor with algorithm functional
7) Man-machine interface operational
8) Compression block operational
9) Communications link and entire system operational
10) A/D interface to CCD operational.

In the following sections, each of the main tasks outlined above are described as specific subtasks. A brief description of the performance objectives for each major technical task is included.

(1.0) Procure and Modify Camera with Fisheye Mounting

The CCD camera is one of the main components to procure. The most appropriate choice would be to obtain the camera from Toshiba who plans to incorporate the high definition CCD array sensor into a camera for the High Definition Television (HDTV) market in Japan. Since HDTV is successful and a large effort is being placed on the HDTV development, this camera should be available well within the Phase II time frame.

The fisheye equipped camera is one of the critical components of the system that would need to be constructed. There are several manufacturers that make fisheye lenses and fisheye lens attachments for 35 mm format cameras. Although fisheye lens adaptors are available for around $100, fisheye lens adaptors are not true fisheye lenses and would not provide the necessary features and image quality. One of the first activities in the development would be the purchase of the lens and a camera interface so that further algorithm testing could be performed early in the program.

A lens reduction element is necessary in order to adapt the fisheye lens image onto the CCD array sensor. The fisheye lens produces a 23 mm effective diameter circular image on normal 35 mm film. The CCD sensor has a useful area of about 10.5 mm so that a 1/2 reduction would need to be obtained. This reduction can be accomplished through a 3 lens arrangement consisting of two reducing lenses and a field lens. This would have to be incorporated between the fisheye lens and the CCD camera. A conceptual picture of the fisheye lens equipped camera is shown in Figure 7.

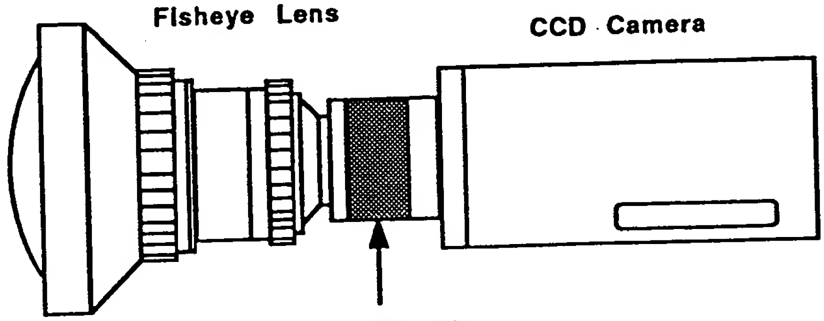

Figure 7 Fisheye Equipped Electro-Optical Camera

Prior to the availability of the camera, efforts would concentrate on the electronics design of the frame buffer and translation buffers that interface to the camera and the communication and digital signal processor designs. The interface to the CCD camera consists of a flash A/D converter interface and timing logic. The A/D converter interface would be defined separately from the camera so that design progress could be made on the memory buffers and digital signal processor interface. The major activities associated with the camera fabrication task are:

1.1 Contact manufacturer for detail on CCD sensor

1.2 Procure camera with high definition CCD sensor

1.3 Procure fisheye lens

1.4 Design lens reduction interface

1.5 Procure lens reduction components

1.6 Fabricate camera

The final result of this activity is a fisheye equipped camera that provides a digitized 180° fisheye view. The interface to the CCD array will be provided by either modifying the camera electronics so that the pixel values can be captured directly or by adding an external interface to digitize the analog information from the camera.

(2.0) Develop Algorithm Software Control Features

The electro-optical camera provides the opportunity to investigate new methods for remote viewing. The viewing conditions are completely determined by the transformation map stored in the transformation buffers. Since these can be controlled completely by software, an endless number of possibilities are at hand. Before a fully functional camera is available, all of the possible display conditions can be investigated by using a fisheye equipped 35 mm camera and a high resolution digitizer. The digitizer would be used to digitize the 35 mm format pictures into the expected resolution of the CCD array sensor for analysis. The selected digitizer would offer a 256 level or 8 bit digital gray scale picture resolution to match the requirements of the electro-optical camera. The digitizer would be interfaced to a personal computer so that a full digitized bit-mapped image can be stored for analysis. The Phase I software would be extended to provide the camera functions and added features. The benefit of this approach is the ability to write the software and define the feature control before the camera is fabricated. These software efforts would be carried out in parallel to the electronics design. The major activities associated with this task are outlined below.

2.1 Procure testbed fisheye lens

2.2 Procure 35 mm camera and mounting

2.3 Procure digitizer

2.4 Develop software interface to digitizer format

2.5 Extend Phase I software to digitizer format

2.6 Develop software feature controls

2.7 Develop man-machine interface concept

The main initiatives for this task are to examine different ways for controlling the viewing format and to investigate operator man-machine interface functions for the final system integration.

(3.0) Design and Prototype Command Channel Link

The command channel provides the low speed communication link to each of the cameras on the network. Its purpose is to provide control information to the camera. The control information would consist of viewing direction (pan and tilt), zoom or magnification, image rotation angle, frame rates and frame attributes, and control information for auxiliary functions. Peripheral control of auxiliary functions are included for convenience in viewing and consists of on/off control of background lighting and lighting levels. The command

channel can be a relatively slow communication link. Possible choices are RS-422 differential with camera to camera repeaters, coaxial, and fiber optic. The coaxial cable and fiber optic communication interfaces are attractive because cameras can be passively connected to the network. This allows cameras to be added or removed from the network during operations without disturbing the working network. The overall objective of this task can be broken down into the following activities:

3.1 Selection of appropriate physical link

3.2 Design physical interface

3.3 Procure electronics and hardware connections

3.4 Assemble and test physical interface

At the completion of this task, a physical interface will be available for testing that provides passive connection onto a multiple camera network.

(4.0) Design and Prototype CCD Frame Buffer Block

The CCD frame buffer consists of a 1024 by 1024 pixel memory buffer for storage of the CCD image as it is read out from the CCD image sensor. The frame buffer is implemented as 8 bit planes to give a minimum gray scale dynamic range of 52 dB. This would be necessary to eliminate the possibility of false contouring in the image. Since the reported dynamic range of the CCD sensor developed by Toshiba is over 70 dB, a very good gray scale picture should be attainable with minimal contouring and noise effects. The image buffer would be updated at a 30 Hz or 30 frame per second rate. This would represent the minimum necessary frame rate to provide a flicker free image in the final display. Readout of the CCD frame buffer can be accomplished as either a 30 Hz non-interlaced or 60 Hz interlaced scan implementation depending on the display monitor. The major activities associated with this task are:

4.1 Selection of video RAM devices

4.2 Design frame buffer and interface

4.3 Procure electronics parts

4.4 Prototype and test design

At the completion of this task, a CCD frame buffer and interface will be available for testing with the remainder of the camera electronics.

(5.0) Design and Prototype Translation Buffer Block

The translation block provides the real-time undistorted image conversion from the contents of the CCD frame buffer block. The translation buffer block consists of a horizontal and vertical translation buffer and a video system controller interface. The horizontal and vertical translation buffers provide the real-time window into the CCD buffer for undistorting the circular fisheye image. The translation buffer readout and addressing rates are controlled by a video system controller (VSC). The VSC performs the display update and refresh cycles for the translation buffers automatically. The VSC is controlled and programmed by the digital signal processor and is reprogrammed only when the frame scan rates are changed. The translation buffer design consists of the following activities:

5.1 Selection of video RAM devices

5.2 Selection of video controller

5.3 Design translation buffer and interface

5.4 Design VSC interface to translation buffer

5.5 Procure electronics parts

5.6 Prototype and test design

At the completion of this task, a translation buffer and interface will be available for testing with the remainder of the camera electronics hardware. The algorithm processor interfaces directly to the translation buffer block through the video system controller. The VSC provides the programmed readout of the the translation buffer and subsequent address look up of the CCD frame buffer.

(6.0) Design and Prototype Algorithm Processor Block

The algorithm processor block is responsible for providing the updated transformation map for the XY translation buffers. In this task, several different digital signal processing options must be considered. Several vendors offer special purpose high speed VLSI digital signal processing circuits. The major considerations are the cost, power consumption, speed, and packaging size of the final camera. It is desirable to use a single-chip solution for the algorithm processor. There are several commercially available digital signal processors that could perform the algorithm calculations at greater than a 1 Hz rate. Most notably are the Analog Devices ADSP-2100, the Motorola DSP56001, the Texas Instruments TMS320 series, and the Harris RTX2000. The selection of the processor core must include consideration for programming tools and language support and the

feasibility of communication with the command channel for camera control. The design of the algorithm processor consists of the following basic design activities:

6.1 Selection of processor

6.2 Procure development system

6.2 Design processor core

6.3 Procure electronic components

6.4 Prototype and test design

6.5 Develop test software for hardware evaluation

The results of this task are to provide a processing core that can provide the algorithm transformations in real-time for camera motion control. The processor will communicate with the control channel to receive commands for electronically controlling the camera view and frame rates. Also, the processor will provide the control inputs to the data compression block to control the bandwidth compression algorithm and frame rates. The processor core can be tested as an entity before it is interfaced to the CCD frame buffer and transformation buffer blocks.

(7.0) Development of Man-Machine Interface

The man-machine interface is provided so that the operator can control the camera network using a high-level graphics and object based interface. The man-machine interface would consist of a general purpose personal computer with a high resolution monitor and appropriate graphics and scanner interfaces. The interface will provide a graphical means for the operator to select and magnify views and to change the operating mode of the viewing system. This task would involve the following objectives:

7.1 Procure computer system

7.2 Procure monitor

7.3 Procure software development language

7.4 Procure graphics tools

7.5 Develop menu control approach

7.6 Develop software menu application

7.7 Develop status presentation displays

7.8 Refine software approach using final camera system

The end result of this task is to provide a simple man-machine interface with graphics based menus for operator control of cameras in the vision control network.

(8.0) Design and Prototype Data Compression Block

The data compression block provides the video bandwidth compression of the undistorted image before transmission over the network. Since there is a limited amount of data bandwidth in a freespace environment situation or even coaxial or fiber optic cable communication links, the desire is to achieve a high degree of bandwidth compression using several different approaches. Research is necessary to determine the best possible methods for optimum bandwidth compression of real-time video information. There are several viable alternatives to video data compression with the amount of bandwidth reduction heavily weighted by the type of picture information being processed. The number of digital bits per sample required is determined by the problems of false contouring rather than by proper gray scale rendition. False contouring leads to edges and gray-scale transitions that were not present in the original picture. Two methods that look most promising at this time are the Differential Pulse Code Modulation DPCM and Vector Quantization approaches. These will have to be investigate in more detail before a particular choice is made. The most important activities associated with this effort are outlined below.

8.1 Selection of bandwidth compression approach

8.2 Design bandwidth compression high level approach

8.3 Design bandwidth compression low level and interface

8.3 Procure electronic hardware

8.4 Prototype and test design

8.5 Incorporate design into final system

The data compression block provides a reduction in the bandwidth or amount of data to be transmitted over the communication link. Once the data is reduced, the high speed communication block can transmit the data at selected frame rates up to the maximum necessary rate of 30 frames per second. The goal is to be able to multiplex via time division and/or inter-frame multiplexing several camera views using a single network link.

(9.0) Design and Prototype High Speed Communication Link

The purpose of the high speed communication link is to provide time multiplexed frame information from several cameras using a single high speed communication link. When multiple cameras are to be utilized in a single remote viewing system, methods of sharing the same communications channel can be applied to minimize the communications overhead for freespace. These include selective frame rate transmission, image bandwidth compression, and variable resolution imaging. In selective frame rate transmission, the frame rate from a particular camera is controlled and can be set to lower rates when the view is not needed for real-time control. For instance, the rate on one camera could be set to 1 frame per second if it is a background picture needed for overall position reference, or if its information is only of small importance. Camera views not needed for the particular remote task could halt transmissions until they are needed. In this manner, the most important camera views needed for the particular task could be time multiplexed over a single high speed network. The major activities associated with this task are:

9.1 Select communication physical channel

9.2 Design multiplexing scheme

9.3 Design transmit and receive interfaces

9.4 Procure electronic components

9.5 Prototype and test design

9.6 Integrate into camera system

The result of this task is to provide a communication link that will enable several cameras to be networked using a single physical communication network.

(10.0) Design and Prototype A/D Interface to Camera

The CCD camera provides a HDTV composite signal for the high definition television standard. This signal must be sampled and digitized by a high speed flash A/D converter at the HDTV scan rates. Alternatively, the A/D interface could be integrated into the camera electronics to digitized the pixel information from the CCD sensor interface electronics. The CCD sensor provides two parallel pixel output paths for each horizontal scan line. This reduces the necessary conversion rate of the A/D converter to a maximum of 37 MHz which is within the sampling rate of commercially available flash A/D converters. This task consists of the following major activities:

10.1 Determination of CCD interface method

10.2 Selection of A/D

10.3 Selection of A/D interface buffer amps

10.4 Procure electronics hardware

10.5 Design, prototype, and test A/D interface

10.6 Integrate into final system

The A/D interface will be implemented as a dual pixel interface. The CCD sensor provides a dual channel readout of the horizontal CCD shift register so that slower clock signals could be used while maintaining a 30 Hz frame update rate. The dual channel A/D interface will provide a dual channel write capability to the CCD frame buffer so that the CCD frame buffer will have to be split into an odd and even pixel arrangement. This odd and even pixel arrangement will have to be considered in the design of the CCD frame buffer block and the XY translation buffer block designs. The address look up and pixel readout of the CCD frame buffer into the data compression block is still on a pixel serial basis so that its design is not affected. The address look up is simply implemented by employing the least significant bit as an odd/even switch between halves of the CCD frame buffer. This represents a very simple solution to the CCD pixel interleaving from the sensor.

6. Key Personnel

Dr. H. Lee Martin - Principal Investigator

SUMMARY OF CAPABILITIES

Dr. Martin has over 8 years of experience in the design, development, testing, and implementation of human controlled manipulation systems for hostile environments. He has exceptional hands on experience with this type of equipment having learned from systems integration on four completely different teleoperated manipulators while employed at the Oak Ridge National Laboratory. He brings TRI a knowledge of mechanical engineering from his educational background that has been augmented with extensive human factors and electrical engineering experience in digital systems. His ability to find simple, alternative solutions to difficult problems has been his forte.

Seeing the potential for growth in the area of robotics applications in remote and/or hostile environments, Dr. Martin founded TeleRobotics International, Inc. in 1986 to provide control and mechanism design

products and services to the industry that is evolving around this technology.

EDUCATION:

B.S.M.E., Univ. of Tennessee,
M.S.M.E., Purdue University,
PhD. in M. E., Univ. of Tennessee,

ENGINEERING EXPERIENCE:

President and Founder of TeleRobotics International, Inc.: Started in to provide design and consultant services in teleoperated and robotic manipulators and digital control systems.

Development Engineer at Oak Ridge National Laboratory: Initiated and led the TeleRobotics Task Force (1985), a group formed to find new research funding opportunities for teleoperation developments. Lead control engineer on the Advanced Servomanipulator development project a force-reflecting manipulation system built for hostile environments. Prior to this activity , he developed software and algorithms for the world's first digitally controlled servomanipulator (the Central Research Lab. Model M-2). Supervised the research of 3 graduate students and over a dozen cooperative education students in addition to several development engineers.

Consultant for REMOTEC Corp.: Developed controls for a remote maintenance device and providing controls and system integration expertise for this firm

Research Assistant at Purdue Univ.: Developed battery state-of-charge indication methods for electric vehicles. This effort later led to a patented device (US patent 4390841) for battery monitoring.

Engineer's aide for T.V.A.: designed nuclear power plants.

PROFESSIONAL INVOLVEMENT:

* National Young Professional Engineer of the Year, U.S., 1988 (Society of Professional Engineers).
* Founding Chairman of the Knoxville/Oak Ridge Subchapter of Robotics International
* Recipient of <u>Industrial Research</u> magazine's **IR100** award in for development of the first digitally controlled servo-

manipulator (noted as one of the 100 outstanding new technical product's of [ ]

* Editor of a technical paper collection <u>Teleoperated Robotics for Hostile Environments</u> published nationally by the Society of Manufacturing Engineers in
* Organizer and lecturer of a tutorial on Remote Handling. This event held in conjunction with the American Nuclear Society Topical Meeting attracted 95 participants from 8 countries.
* Technical review committee and session co-chairman for ANS Topical Meeting on Remote Handling in [ ]
* Outstanding Young Manufacturing Engineer, [ ] Society of Manufacturing Engineers (12 nationally).
* Young Professional Engineer of the Year, State of Tennessee,
* Registered Professional Engineer in Tennessee.
* Member of the American Society of Mechanical Engineers.
* Member of the Society of Manufacturing Engineers, Robotics International.

Steven D. Zimmermann-Research Associate

<u>SUMMARY OF CAPABILITIES:</u>

Mr. Zimmermann has a strong background in the design and fabrication of analog and digital electronics He has independently developed and designed several control components for remote manipulator systems including a self-contained control pendant for operator interface with remote auxiliary equipment, a joint processor network for robotic sensing and control, and a communications network for telerobotic operations. His expertise in surface mount technology assures that his solutions are not only functional, but packaged as small as possible with today's technology. His experience with real-time controls and his ability to integrate software and hardware allow Mr. Zimmermann to efficiently accomplish seemingly impossible tasks. His balance between algorithms, software, and hardware is unique and exceptional. Mr. Zimmermann is considering the opportunity of developing a Master's thesis around this Phase II proposal utilizing these algorithmic and hardware developments as the subject of a thesis on real-time image enhancement.

EDUCATION:

B.S.E.E., University of Tennessee,

M.S.E.E., Candidate, University of Tennessee

ENGINEERING EXPERIENCE:

Electrical Engineer, TeleRobotics International, Inc.

Responsible for the development and implementation of robotic control systems, software support, and circuit design. Efforts have included the development of an Application Specific Integrated Circuit for manipulator joint control, development of transformation algorithms for remote viewing, and development of communications links for manipulator operations.

Development Engineer, Oak Ridge National Laboratory, Hardware/software design of robotic and master/slave servomanipulator systems including the Advanced Servomanipulator and the Laboratory Telerobotic Manipulator.

Summer Engineering Intern, Texas Instruments (Summer Hardware design of very high speed integrated circuits (VHSIC) for military processing applications.

Student Engineering Assistant, Technology for Energy Corp.

Worked in product development performing hardware design and development for nuclear power plant instrumentation.

PROFESSIONAL INVOLVEMENT:

* Member of Tau Beta Pi
* Member of Eta Kappa Nu

Paul E. Satterlee, Jr. - Research Associate

SUMMARY OF CAPABILITIES

Mr. Satterlee is an expert in the development of real-time control systems for unique applications. He has the ability to match algorithm requirements, input/output needs, and computational hardware capabilities to build systems that function extremely well. This ability has been gained from the application of digital control systems to several robotic and teleoperated manipulator systems including hardware architecture, design of components, and construction of system software. He has become an expert at the programming language FORTH and has developed several libraries of functions related to robotic and teleoperated manipulator controls.

Mr. Satterlee was the sole control system hardware designer of the award winning Model M-2 manipulator system at the Oak Ridge National Laboratory. His present research interests are in the application of artificial intelligence to real-time control applications.

EDUCATION:

B.S.E.E., Louisiana State University,

M.S.E.E., Louisiana State University,

ENGINEERING EXPERIENCE:

Vice President, Computer Systems, TeleRobotics International, Inc. Founding partner in TRI to explore research in the area of future manipulator systems.

Telerobotic Systems Consultant, developed control system hardware and software for a mobile surveillance robot and master/slave servomanipulators for Remote Technology Corp. in Oak Ridge, Tennessee.

Staff Engineer, Oak Ridge National Laboratory, hardware/software design of robotic and master/slave servomanipulator systems, microprocessor-based smart instruments, data acquisition systems, and other process control systems.

Consultant, University of Tennessee to the Oak Ridge National Laboratory Instrumentation and Controls Division, researching Computer Aided PLC Programming.

Graduate Research Associate, University of Tennessee, designed and built prototype microprocessor-based, programmable data collection platform under NASA contract.

Engineer, WWL TV-FM-AM broadcast stations, New Orleans, Louisiana, worked as cameraman, video controller, video tape, projection, and transmitter duty.

PROFESSIONAL INVOLVEMENT:

* Member of Eta Kappa Nu (Electrical Engineering Honor Society).
* Certificate of Merit for "Best Paper" at the 29th RSTD Conference.
* Industrial Research IR-100 Award for the development of the "M-2 Digital Control for Servomanipulator".

RELEVANT PUBLICATIONS OF INVOLVED TRI PERSONNEL

1. "Applying the Novix Computer to Real-time Control of Redundant Teleoperator and Robotic Manipulators", Final report, U. S. DOE contract DE-AC05-86ER80406,

2. "Design Enhancements for the Advanced Servomanipulator", Final report, U. S. DOE contract DE-AC05-86ER80399,

3. "Development of Dual-Arm Robotic Manipulator Control Based on Teleoperated Manipulation Methods", Final Report, NASA contract NAS1-18423.

4. "Integrated Digital Control and Man-Machine Interface for Complex Remote-Handling Systems," International Topical Meeting on Remote Systems and Robotics in Hostile Environments,

5. SURBOT: A Surveillance Robot System for Use in Nuclear Power Plants, Robot: Conference, Chicago, IL,

6. Mobile Surveillance Robot System, Proceedings of the American Nuclear Society Topical Meeting on Robotics and Remote Handling in Hostile Environments, Salt Lake City, UT,

7. "Surveillance Robot for Nuclear Power Plants," Proceedings of the American Nuclear Society Remote Systems Technology Division, San Francisco, Ca.,

8. "The State-of-the-Art Model M-2 Maintenance System," Proceedings of the American Nuclear Society Topical Meeting on Robotics and Remote Handling in Hostile Environments, Gatlinburg, Tn.,

9. "Control Software Architecture and Operating Modes of the Model M-2 Maintenance System," Proceedings of the American Nuclear Society Topical Meeting on Robotics and Remote Handling in Hostile Environments, Gatlinburg, Tn.,

10. "Distributed Digital Processing for Servomanipulator Control," Proceedings of the American Nuclear Society Remote Systems Technology Division Conference, Washington, D.C.,

11. "Electromechanical Three-Axis Development for Remote Handling in the Hot Experimental Facility," Proceedings of the American Nuclear Society 29th Remote Systems Technology Division Conference, San Francisco, Ca.,

12. "Robotics-Related Technology in the Nuclear Industry", Society of Photo-Optical Instrumentation Engineers,

13. "Control and Electronic Subsystems for the Advanced Servomanipulator", National Topical Meeting on Robotics and Remote Handling in Hostile Environments,

14. "Automatic Camera Tracking for Remote Manipulators", National Topical Meeting on Robotics and Remote Handling in Hostile Environments,

15. "An Advanced Remotely Maintainable Force-Reflecting Servomanipulator Concept", lational Topical Meeting on Robotics and Remote Handling in Hostile Environments,

16. "Joining Teleoperation with Robotics for Remote Manipulation in Hostile Environments", Robots 8, Robotics International of the Society of Manufacturing Engineers,

17. "Evaluation of Robotic Inspection Systems at Nuclear Power Plants", NUREG / CR-3717,

18. "Robotic Design Analysis Based on Teleoperated Manipulator Data Collection", Robots 9, Robotics International of the Society of Manufacturing Engineers,

19. Teleoperated Robotics for Hostile Environments, Editor, Society of Manufacturing Engineers,

20. "Teleoperated Robots - The Manipulation Side of Nuclear Remote Maintenance Systems", Sidebar article for IEEE Spectrum,

21. "Duty Cycle Analysis of a Human-Controlled Robot", Journal of Robotic Systems

22. "Conversion of a Servomanipulator from Analog to Digital Control" IEEE International Conference on Robotics and Automation, San Francisco,

23. "Recommendations for the Next Generation Space Telerobot", Technical Memorandum 9951, Oak Ridge National Laboratory,

7. Facilities/Equipment

TeleRobotics International, Inc. operates a laboratory/office facility in Knox County, Tennessee. These facilities will supply the workspace and most of the equipment required for this effort. Special support for printed circuit board fabrication will be contracted as required for prototype development. Design computational facilities are already available, as are the necessary software design and simulation tools needed for this activity (extensive use of automated circuit layout and simulation tools available at TeleRobotics International, Inc. will be required during this effort).

The unique requirement for the programming of a Digital Signal Processor will require the purchase of a DSP development system to support this specific effort. One station is estimated in the budget. Due to the extremely fast response of the video circuitry required for this project, a high frequency response scope is also required for the testing portion of this effort. The scopes presently used at our facilities do not have adequate response ranges for this purpose, therefore a high frequency bandwidth oscilloscope is also estimated in support of this effort. Other parts and equipment in the budget are directly related to the fabrication of the prototype systems for delivery to NASA.

The majority of the effort is reduction of concept to practice. Since we validated the algorithm in the Phase I effort, the only question remaining is one of speed of the electronics. Our efforts will therefore focus on design, implementation, and testing. Special equipment requirements are limited to those described above.

8. Consultants

Dr. Don Bouldin and Danny Newport will consult on this effort to provided Application Specific Integrated Circuit tools to enable the designs developed in the Phase II effort to be miniaturized for commercialization. They are experts in the field of Computer Aided Design Tools for the development of ASICs and have supported our efforts in the past on other comparable activities. A statement of work and an estimate from Dr. Bouldin for development of ASIC tools and implementation of an ASIC chip has been obtained for the purpose of the budget estimates enclosed.

9. Budget

Form 3090-0116 is attached along with supporting break out information per instructions of Table 15-2. Additional materials

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support is also provided for the cost of key components in the design. Where possible, cost estimates are based on data sheets and/or vendor contact. In specific instances where subcontracted fabrication is required, engineering judgement was used to estimate the cost of the prototype fabrication based on past experiences.

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